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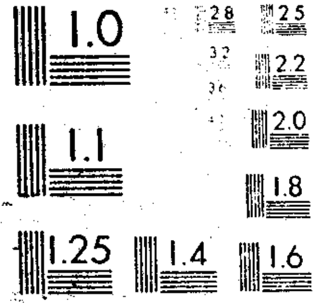

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16. Abstract

Twelve overweight male subjects were evaluated once on a normal diet and once on a 24-h crash diet (low-calorie liquids only). Experiments were 1 wk apart. During 2¼-h complex performance tests given at the end of the diet period, subjects breathed an O_2/N_2 gas mixture equivalent to 12,500 ft. There were no significant physiological and biochemical findings due to diet for heart rate, blood pressure, serum electrolytes, subjective fatigue and urinary excretion of K^+, epinephrine and norepinephrine. Body temperatures were lower ($p < .05$) for the crash diet than for the normal diet. Serum glucose levels were normal but increased during the normal diet and decreased during the crash diet. Hematocrit increased from pretest to posttest under both conditions but was greater for the crash diet ($p < .05$) than for the normal diet Urinary excretion of 17-ketogenic steroids was less ($p < .001$) for the sleep period for the crash diet than for the normal diet. Urinary excretion rate of Na^+ was less ($p < .001$) for the crash diet than for the normal diet. Complex performance showed no significant differences when subjects were tested under low workloads. Several measurements showed enhancement of performance during the crash diet when subjects were being tested under the medium and high workload conditions.

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PHYSIOLOGICAL, BIOCHEMICAL, AND PERFORMANCE RESPONSES TO A 24-HOUR CRASH DIET

INTRODUCTION

The problem of obesity in the American population is receiving increased attention, by both medical and lay writers. Victor Cohn (7), in a recent article in the Washington Post, states:

> Americans are too fat and getting fatter. Despite a new nationwide passion for exercise...only one group, white middle- and upper-class women past their 20's so far have been getting thinner. Obesity has reached epidemic proportions, say the medical experts, and too much weight remains one of the most important medical and public health problems of our time.

As Cohn points out, there have been improvements in certain socioeconomic groups, but statistics derived from the population in general are not so reassuring. In fact, numbers of both men and women who were at least 20 percent overweight increased during the period 1971-1974 in comparison to the prior survey period 1961-1962 (4).

According to Federal Aviation Administration (FAA) statistics derived from the population of active airmen during the period 1969-1979, the average weight-to-height ratio for male pilots increased during the observation period (1,2). Using guidelines recommended during the Fogarty Center Conference on Obesity in 1973 (3), it can be calculated that the average male pilot is 22.7 lb above the average acceptable weight. Female pilots on the other hand were found to be somewhat less obese, although their average weight was 9.1 lb over the average acceptable level for their height; this figure remained at least 10.0 lb under the maximum acceptable weight. Thus, female pilots tend to be less overweight than males and approximate the middle-class and upper-class women mentioned by Cohn (7).

The recognition of an increased prevalence of obesity and descriptions of it as "a hazard to health and a detriment to well-being" (4) have led to a great increase in the number of strategies for correcting the problem. One of these methods, the crash diet, is worthy of consideration as a potential threat to aviation safety for the following reasons: (i) Although other regimens usually provide for some kind of caloric intake, the crash diet requires a complete abstinence from all food for at least 24 h. Such fasting has been shown to effect a number of physiological and metabolic changes, including shifts in body water (8) and mobilization of fat stores (19). (ii) Common experience tells us that abstinence from food for any period can produce some discomfort which can distract those occupied in vigilance tasks or complex psychomotor tasks such as those associated with flying.

METHODS

Twelve subjects were evaluated on two occasions, once while they were eating a normal diet and once after they had consumed only low-calorie liquids for over 24 h before the experimental session. Six subjects were fed during their first experiment and dieted on the second experiment; the other six subjects experienced reverse order of fasting and feeding. All subjects were healthy, male, paid volunteers who were 5 to 15 percent overweight. The weight-per-height norms of the Framingham Study (9) were the basis for calculating the degree of overweight. The physical characteristics for the subjects are listed below in Table I.

TABLE I. Physical Characteristics of Study Participants

Characteristic	Mean	Range
Age (yrs)	24.25	18-32
Height (cm)	180.00	171-186
Weight (kg)	92.30	79.1-106.8
Weight-to-Height Ratio (kg/cm)	0.51	0.46-0.58

Each subject was required to pass an FAA Class III medical examination. Each was fully informed about the experiment and told that he could withdraw from the study at any time. Each participant was given four 3-h training sessions on the Civil Aeromedical Institute's (CAMI) Multiple Task Performance Battery (MTPB) to be described later in this section.

After training, subjects underwent two 28-h experiment sessions held 1 wk apart. Subjects reported to the laboratory at 0700 and were fed a standard breakfast. During the sessions in which the subjects were fed, the subsequent meals were served at 1200 and 1700 the first day and at 0700 the following morning. All breakfasts consisted of two scrambled eggs, two slices of bacon, two slices of toast with butter and jelly, and milk and coffee. Lunch and supper consisted of one meat dish, two vegetables, bread, dessert and drink. At 0800 the first day, they received a 2½-h refresher training session on the MTPB. At 1015 they voided and discarded urine, emptying the bladder as completely as possible. After this, urine was collected for periods ending at 2200 the first day, at 0630 the following morning (the overnight/sleep period) and at 1030 when the experiment was concluded. Urine volumes were recorded and portions of each sample frozen for later analyses of 17-ketogenic steroids (11), catecholamines (12) and the electrolytes Na^+ and K^+ which were measured with an atomic absorption-emission spectrophotometer (Instrumentation Laborator Inc., Model 353).

At approximately 1030 the first day, the first venous blood sample was drawn (baseline). At the conclusion of the experiment, at approximately 1030 the second day, a final blood sample was drawn. These samples were analyzed for hematocrit and blood glucose. Plasma from these samples was frozen and later analyzed for Na^+ and K^+ levels.

Subjects were weighed at the beginning and at the end of the experiment. Rectal thermistor probes were inserted for internal body temperature measurements (T_{re}), which were recorded hourly from 1100 the first day through 1000 the second day. Subjects were also fitted with adhesive chest electrodes which were connected to an electromagnetic tape recorder for continuous heart rate (HR) recording. Each subject filled out the first Fatigue Checklist (FCL) (22) at 1030 on the first day. Additional FCL's were completed at 1500 and 2200 the first day and at 0630 and 1030 on the following day.

Subjects slept in a dormitory from 2230 the first evening to 0615 the following morning. The 2½-h MTPB test sessions were administered from 0800 to 1015 on the second morning. During the MTPB test sessions, subjects breathed a gas mixture containing 13.3 to 13.4 percent oxygen in nitrogen. This mixture provides a partial pressure of oxygen approximately equivalent to 12,500 ft (3,810 m) of altitude. Subjects breathed room air through the masks during several of the training sessions; the masks were adjusted to assure a proper fit for each subject.

The CAMI MTPB was used to measure time-shared performance in up to six component tasks simultaneously. The MTPB system is computerized; task presentation and data collection are automatic. The test panel displays and response controls are depicted in Fig. 1. The system has been described in detail (13). A brief description follows:

Tasks 1 and 2: Monitoring of Red and Green Warning Lights.

This is a choice/reaction time task involving the monitoring of five green lights (normally on) and five red lights (normally off). The 10 lights were arranged in pairs of green and red. One pair is located in each corner of the test panel and a fifth pair is located in the center of the panel. The light lenses also serve as the pushbutton/switch. The subject was instructed to push the light/switch whenever the light changed state. The measures of performance on this task are mean and standard deviation of response latency and percent signals detected. These measures are recorded separately for red and green lights.

Task 3: Monitoring of Meters.

This task involves monitoring four meters whose pointers move at random around a vertical position. The subject responds to a shift in the mean position of the pointer by pressing one of two buttons under the meter to report a left or right shift. The four meters are arranged across the top of the test panel. Performance measures are mean and standard deviation of response latencies and percent signals detected.

Task 4: Mental Arithmetic.

The subject is required mentally to add two numbers and subtract a third number from the sum of the first two. All numbers are of two digits. Answers are recorded by a 10-key response panel. The arithmetic task display is located in the lower center of the test panel with the keyboard to the right of the display. Performance measures are the mean and standard deviation of response latency and percent correct answers.

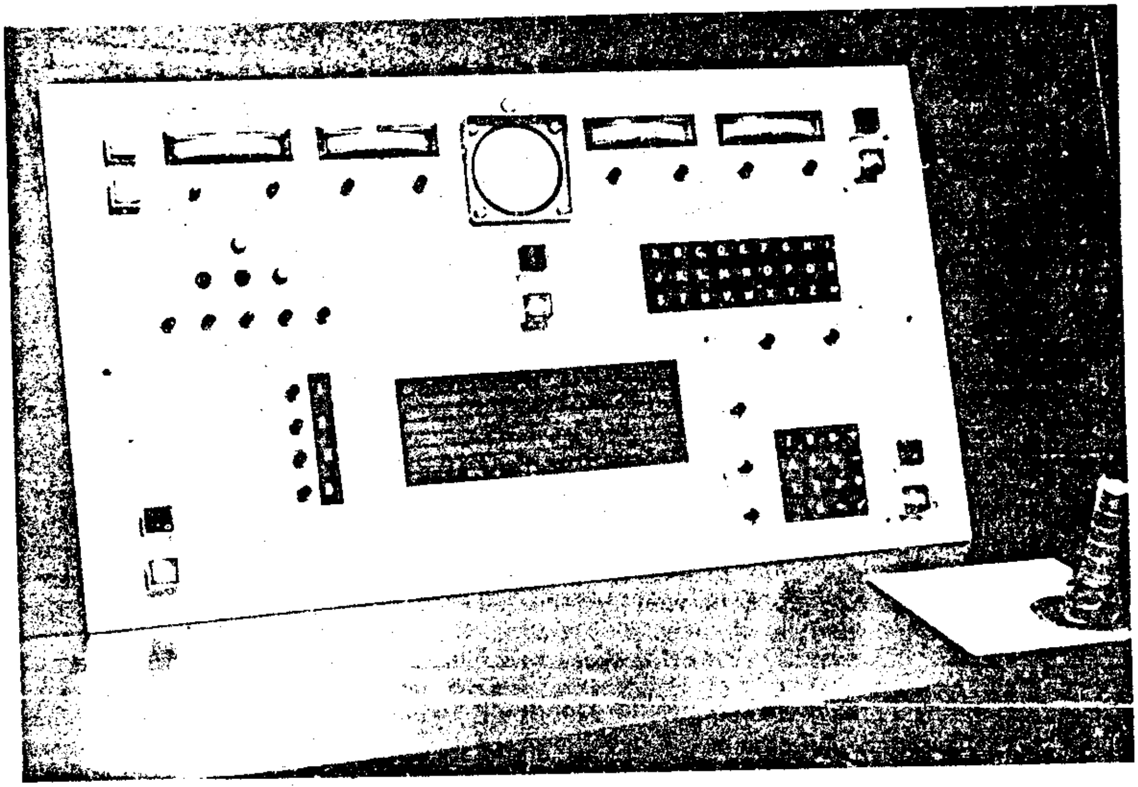

Figure 1. Console of the Multiple Task Performance Battery

Task 5: Two-Dimensional Compensatory Tracking (TRK).

The tracking task display is an oscilloscope screen mounted in the top center of the subject's panel. The target on the screen is a dot of light about 1 mm in diameter. A varying amplitude disturbance is imparted to the target in each dimension; the subject attempts to counteract the disturbance, keeping the dot at center screen, by moving a control stick with his right hand. Performance is measured by analog circuitry in terms of mean integrated absolute error and mean error squared for both horizontal and vertical dimensions. These data are converted to measures of absolute vector error and root-mean-square vector error.

Task 6: Problem Solving (PS).

Each test panel is equipped with five response buttons, a "task active" light, and three "feedback" lights, all located at the left center of the test panel. The problem is to discover the correct sequence in which to press the five response buttons. Each button appears only once in a given trial. Subjects are instructed to use a trial-and-error procedure and a left-to-right search pattern. An amber feedback light is illuminated every time a button is pressed to show that the response is acknowledged by the system. Pressing buttons in incorrect order causes a red light to turn on and stay on until the next correct response is made. Pushing all five buttons in correct order causes a blue light to turn on. When a problem is solved, a lapse of 15 seconds occurs, following which the same problem is presented a second time. The subject is expected to reenter the previous solution from memory on the second, or confirmation presentation. After another 15 seconds a new problem is presented. Performance measures for this task are: (i) mean response latency in the solution stage (time to solve the problem divided by the total number of responses); (ii) mean response latency in the confirmation stage; (iii) the standard deviation of response latencies for the solution; (iv) the standard deviation of response latencies for the confirmation; (v) the percentage of "non-redundant" responses made during the solution phase; and (vi) the proportion of "correct" responses made during the confirmation phase.

MTPB Procedure. A basic 45-min schedule of the five MTPB tasks was used. This 45-min period was divided into three 14-min intervals. Tests 1, 2 and 3 were given throughout the schedule. In the first interval of each period, Test 4 was also active. In the third interval, Tests 4, 5 and 6 were active.

These three-interval schedules were named the low, medium and high workload conditions, respectively, and were always presented in the same order in each period.

The four practice sessions were each of four 45-min periods. The experimental test sessions and the "refresher" practice sessions given 24 h prior to each experimental test were each three 45-min periods.

Performance was assessed in terms of raw and composite scores for each task. Composite scores summarized all measures of performance for the particular task. An overall composite score (all subjects) was also obtained. Individual composite scores were calculated as follows: for each raw data measurement on each task, the scores for each subject over all experimental treatments were converted to standard scores with a mean of 500 and a standard deviation of 100. Thus, the task score for each subject and experimental treatment was the mean of standard scores on each performance measurement. An overall composite score was also calculated for each subject and treatment by averaging the composite scores for different tasks so that each task made an equal contribution to the variance. Analyses of task and overall composite scores were made because they: (i) simplify the evaluation of a large amount of data; (ii) have been found to be more sensitive to the effects of experimental conditions than the individual measurements of performance; and (iii) have higher reliability than raw score data on individual performance measures (6,14).

RESULTS

All physiological and biochemical data were treated by analysis of variance techniques (25).

Weight. Table II shows the mean weights before and after each experiment.

TABLE II. Weight (kg)

	Crash Diet		Normal Diet	
	Pretest	Posttest	Pretest	Posttest
Mean	93.25	91.89	92.85	92.66
S.D.	±7.57	±7.51	±7.51	±7.48

Subjects demonstrated no statistically significant difference for their pretest weights for the two experimental conditions. There was also no significant difference between the pretest and posttest weights when subjects had the normal diet. As anticipated, the only statistically significant difference ($p < .001$) was found for the pretest vs. the posttest weight in the crash-diet condition.

Fatigue Checklist. Scores on the FCL can range from 0 to 20; the lower the score, the more fatigued the individual feels. The FCL's were administered periodically during the experiments and the results are presented in Table III by time of day in sequential order.

TABLE III. Fatigue Checklist (points)

Time	Condition	Mean	S.D.
1030	Crash Diet	12.4	±2.9
	Normal Diet	10.6	±3.8
1500	Crash Diet	11.1	±1.7
	Normal Diet	10.0	±3.6
2200	Crash Diet	7.3	±2.2
	Normal Diet	8.5	±3.1
0630	Crash Diet	10.7	±2.5
	Normal Diet	10.4	±4.1
1030	Crash Diet	10.8	±3.0
	Normal Diet	11.4	±3.6

These data were treated by analysis of variance (25). There was no statistically significant difference due to the diet. There was, however, a significant difference ($p < .01$) for time of day, with the greatest fatigue being reported at the end of the first day regardless of diet.

Blood Pressure. Blood pressure measurements were taken at 1130, 1500 and 2200 the first day and at 0630 and 1015 the second day of the experiment. Neither systolic pressure, diastolic pressure nor pulse pressure demonstrated any statistically significant differences due to diet. The analysis of variance yielded a difference for time of day, with systolic pressure ($p < .01$) and pulse pressure ($p < .001$) being greatest at the end of the experiment and the diastolic pressure being greatest ($p < .05$) just before retiring the first evening.

Serum Glucose. The serum glucose levels are presented in Table IV. None of the individuals exhibited any unusual drop in serum glucose level as a result of the crash diet. The lowest value recorded was 70 mg percent. There was, however, a statistically significant difference ($p < .01$) between the crash-diet condition and the normal-diet condition, with a decline of 2.2 mg percent during the crash diet and an increase of 3.8 mg percent during the crash diet and an increase of 3.8 mg percent during the normal diet.

TABLE IV. Serum Glucose (mg percent)

	Crash Diet		Normal Diet	
	Pretest	Posttest	Pretest	Posttest
Mean	86.6	84.4	89.9	93.6
S.D.	±9.7	±9.5	±8.1	±6.1

Internal Body Temperature. Rectal temperatures were recorded hourly and then meaned for three reporting periods--the first day, the overnight (sleep) period, and the second day of the experiment. The results of the T_{re} measurements are reported in Table V.

TABLE V. Internal Body Temperature (°C)

	Day 1		Overnight		Day 2	
Diet	Crash	Normal	Crash	Normal	Crash	Normal
Mean	37.12	37.29	36.51	36.55	36.99	37.06
S.D.	±0.37	±0.16	±0.15	±0.20	±0.19	±0.20

There was a statistically significant difference due to the reporting period ($p < .001$) with the overnight readings being the lowest. There was a significant difference due to diet ($p < .05$) with the crash-diet readings being lower than the normal-diet readings.

Heart Rate. HR, although recorded continuously, was separated into three reporting periods as was the case with T_{re}. The results of the HR measurements are reported in Table VI. There was a highly significant difference ($p < .001$), for the period reported, with the lowest HR overnight. There was no significant interaction between diet and reporting period. Although the HR was lower during the crash diet than during the normal diet for each period reported, the decrease was not statistically significant ($p = .069$).

TABLE VI. Heart Rate (beats per minute)

Diet	Day 1		Overnight		Day 2	
	Crash	Normal	Crash	Normal	Crash	Normal
Mean	82.6	87.9	73.6	74.8	91.8	93.0
S.D.	±9.7	±12.4	±8.5	±9.8	±6.8	±7.4

Hematocrit. Hematocrit measurements were made pretest and posttest for both experiments. The results are presented in Table VII. By analysis of variance, the findings were: (i) an increase from pretest to posttest ($p < .001$), with a greater increase occurring during the crash diet; and (ii) a significantly higher hematocrit for the crash diet than for the normal diet ($p < .05$). There were no significant interactions.

TABLE VII. Hematocrit (percent red cells)

	Crash Diet		Normal Diet	
	Pretest	Posttest	Pretest	Posttest
Mean	47.94	50.69	47.44	49.25
S.D.	±1.24	±1.65	±1.72	±2.05

Serum Electrolytes. The pretest and posttest blood samples were analyzed for the serum Na^+ and K^+. There were no significant findings.

Urine Electrolytes. Urine samples were also analyzed for Na^+ and K^+. The findings are given in Table VIII. For the urinary Na^+ excretion rate, collection periods were significantly different at the $p < .001$ level, with the overnight values being much lower than the daytime values. The crash-diet values were significantly lower than the normal-diet values ($p < .001$). There was no significant interaction. For K^+, the only significant finding was for the period of collection, with the overnight values being lower than the daytime values ($p < .001$). The Na^+/K^+ ratio, on the other hand, demonstrated no difference for time of collection, indicating that when one electrolyte dropped significantly so did the other. The ratios were highly significant for diet ($p < .001$) with ratios being higher for the normal diet than for the crash diet. There was also a significant interaction between time of collection and diet, with the ratio of crash-diet values to normal-diet values greatest for the second morning and least for the first day ($p < .02$).

Urine Catecholamines. The urinary excretion rates of catecholamines are listed in Table IX (epinephrine (E)) and Table X (norepinephrine (NE)). They are reported for the same time periods as the urinary excretion rates of the electrolytes. There were no statistically significant effects due to diet, nor was there any significant interaction between diet and time of collection. There were, however, significant effects ($p < .001$) for time of collection, with the 1030 collection of the second day demonstrating the highest values for both E and NE.

TABLE VIII. Urine Electrolytes

Na^+ Excretion Rate (milliequivalents per hour)

Time	Condition	Mean	S.D.
2200	Crash Diet	6.66	±2.44
	Normal Diet	9.56	±3.45
0630	Crash Diet	3.01	±1.02
	Normal Diet	5.24	±2.54
1030	Crash Diet	4.77	±1.26
	Normal Diet	9.16	±3.97

K^+ Excretion Rate (milliequivalents per hour)

Time	Condition	Mean	S.D.
2200	Crash Diet	2.06	±0.71
	Normal Diet	2.12	±0.83
0630	Crash Diet	1.08	±0.46
	Normal Diet	1.24	±0.47
1030	Crash Diet	2.45	±0.81
	Normal Diet	2.61	±0.58

Na^+/K^+ (ratio)

Time	Condition	Mean	S.D.
2200	Crash Diet	3.61	±1.69
	Normal Diet	5.15	±3.61
0630	Crash Diet	2.99	±1.00
	Normal Diet	4.70	±3.11
1030	Crash Diet	2.23	±1.20
	Normal Diet	3.79	±2.00

TABLE IX.

Urinary Epinephrine Excretion Rate
(micrograms per hour)

Time	Condition	Mean	S.D.
2200	Crash Diet	553.9	±176.4
	Normal Diet	681.6	±255.0
0630	Crash Diet	403.7	±180.7
	Normal Diet	318.3	±130.8
1030	Crash Diet	1089.8	±447.9
	Normal Diet	1014.8	±265.7

TABLE X.

Urinary Norepinephrine Excretion Rate
(micrograms per hour)

Time	Condition	Mean	S.D.
2200	Crash Diet	2044.7	±699.4
	Normal Diet	2393.1	±956.9
0630	Crash Diet	2250.8	±1074.9
	Normal Diet	2232.1	±1221.7
1030	Crash Diet	3510.2	±1570.3
	Normal Diet	3963.8	±949.7

TABLE XI.

Urinary 17-Ketogenic Steroid Excretion Rate
(milligrams per hour)

Time	Condition	Mean	S.D.
2200	Crash Diet	0.4635	±0.4032
	Normal Diet	0.3857	±0.2087
0630	Crash Diet	0.3402	±0.1521
	Normal Diet	1.0045	±0.3957
1030	Crash Diet	0.9227	±0.5598
	Normal Diet	0.7098	±0.2087

Urine 17-Ketogenic Steroids. The urinary excretion rate data of the 17-ketogenic steroids is found in Table XI. It is reported for the same time periods as the other urinary excretion measurements. There were statistically significant differences for time of collection ($p < .01$) for both diet conditions, with the excretion rate of 17-ketogenic steroids being greatest during the second morning for the crash diet and greatest overnight for the normal diet. The only statistically significant difference due to the diet was for the overnight collection period, with the values lower ($p < .001$) for the crash diet than for the normal diet.

COMPLEX PERFORMANCE.

Composite Score Data. The overall composite score data (treatment means and standard deviations) are shown in Table XII as a function of diet for each of the three periods of an experimental session. Overall composite performance scores were significantly higher ($p < .05$) in the fasting condition than in the normal-diet condition. Overall performance was also significantly lower in the second and third periods of a session compared to the first period.

Composite scores (means and standard deviations) for each task are shown in Table XIII for the main effects of diet, workload and period. These data show that the significant effect of diet in overall scores was due to higher performance in the fasting condition in three tasks--the monitoring of green lights, monitoring of meters and mental arithmetic. Increasing workload produced a significant ($p < .01$) decline in performance in the same three tasks, in tracking, and in problem solving. Performance was generally highest in the first period of an experimental session and lowest in the second period. Slight recovery was typical in the third period in all tasks but tracking and meter monitoring. The main effect of test period was significant in meter monitoring ($p < .05$) and mental arithmetic ($p < .01$).

Table XIV shows the significant interaction ($p < .01$) of diet with workload in meter monitoring. In both diet conditions, meter monitoring performance was similar in the low workload condition and decreased with increasing workload, but the decline was less in the fasting condition. This interaction of diet with workload was also present in green light monitoring and mental arithmetic scores, but was not statistically significant.

TABLE XII. Overall Composite Scores as a Function of Diet and Period

Test Period	1	2	3
Crash Diet			
Mean	532	500	508
S.D.	±35.3	±30.2	±25.6
Normal Diet			
Mean	508	472	481
S.D.	±24.6	±34.9	±34.1

TABLE XIII.

Composite Scores for Individual Tasks for the Main Effects of Diet, Workload and Period

Task		Diet		Workload			Test Period		
		Crash	Normal	Low	Medium	High	1	2	3
Green Lights	Mean	526	474**	532	493	475**	510	490	499
	S.D.	82.4	75.8	85.6	75.4	76.2	74.3	76.7	86.3
Red Lights	Mean	499	501	509	501	490	517	488	495
	S.D.	73.4	70.8	73.6	67.8	74.9	62.9	82.0	71.4
Meters	Mean	518	482*	553	507	440**	524	491	484*
	S.D.	60.4	67.6	51.2	58.9	81.9	61.3	67.2	63.5
Arithmetic	Mean	519	481*	537	----	463**	528	471	501**
	S.D.	79.4	82.8	76.3	----	72.3	86.3	81.5	71.1
Problem Solving	Mean	505	495	----	551	449**	512	481	507
	S.D.	65.1	78.0	----	43.6	57.8	75.5	73.1	63.1
Tracking	Mean	504	496	----	570	430**	520	494	486
	S.D.	86.8	97.8	----	71.1	48.1	109.6	86.8	74.2

* = Statistical significance at or below the .05 level.
** = Statistical significance at or below the .01 level.

TABLE XIV.

Composite Scores for Monitoring of Meters as a Function of Diet and Workload

Diet	Workload		
	Low	Medium	High
Crash	551	527	475
Normal	555	488	404

TABLE XV.

Composite Scores for Mental Arithmetic Performance as a Function of Workload and Period

Workload	Test Period		
	1	2	3
Low	580	511	521
High	475	431	482

TABLE XVI.

Composite Scores for Tracking Performance as a Function of Workload and Period

Workload	Test Period		
	1	2	3
Medium	612	562	535
High	428	426	436

TABLE XVII.

The Main Effects of Diet, Workload and Period for Individual Performance Measures in Each Monitoring Task

Task		Diet		Workload			Test Period		
		Crash	Normal	Low	Medium	High	1	2	3
Green Lights									
Mean Response Latency (ms)	Mean	4339	5384	4338	4882	5366**	4596	5010	4979
	S.D.	2134	2585	2303	2466	2401	2484	2145	2607
Intrasubject S.D. of Resp. Latency (ms)	Mean	3994	4859*	3990	4412	4877*	4241	4607	4431
	S.D.	1949	1692	1984	1847	1677	1984	1719	1896
Percent Detected	Mean	86.7	78.0**	89.8	79.6	77.7**	83.6	80.9	82.5
	S.D.	15.5	19.8	14.7	16.6	20.7	19.0	16.3	19.4
Red Lights									
Mean Response Latency (ms)	Mean	2793	2732	2987	2507	2795	2580	2910	2798
	S.D.	2032	1975	2670	1491	1605	2157	1894	1938
Intrasubject S.D. of Resp. Latency (ms)	Mean	1637	1617	1519	1593	1769	1330	1756	1796
	S.D.	2018	1676	1994	1755	1799	1590	1942	1973
Percent Detected	Mean	95.4	98.3	96.5	96.8	97.3	98.0	96.5	96.0
	S.D.	12.1	6.4	11.6	8.7	8.6	8.3	10.2	10.5
Meters									
Mean Response Latency (ms)	Mean	20625	24741	15376	22345	30327**	19456	23609	24983
	S.D.	14277	16837	10039	14389	17998	14445	15770	16425
Intrasubject S.D. of Resp. Latency (ms)	Mean	13755	16733*	10818	15451	19463**	13573	15460	16699
	S.D.	8491	9448	7023	8971	9026	9313	8497	4209
Percent Detected	Mean	95.0	91.9	98.1	94.9	87.3*	95.5	93.0	91.8
	S.D.	14.3	18.1	9.2	13.1	22.0	11.9	17.8	18.3

* = Statistical significance at or below the .05 level.
** = Statistical significance at or below the .01 level.

TABLE XVIII.

The Main Effects of Diet, Workload and Period for Individual Performance Measures in the Mental Arithmetic and Tracking Tasks

Task		Diet		Workload			Test Period		
		Crash	Normal	Low	Medium	High	1	2	3
Arithmetic									
Mean Response Latency (ms)	Mean	10263	11050	10120	-----	11192**	10002	11214	10753**
	S.D.	1776	2551	2172	-----	2163	2054	2197	2272
Intrasubject S.D. of Resp. Latency (ms)	Mean	3831	4415**	3614	----	4632**	3877	4403	4089*
	S.D.	1112	1179	1274	----	1083	1272	1303	1228
Percent Correct	Mean	93.9	91.8	94.3	----	91.3**	94.2	91.7	92.6
	S.D.	7.2	10.7	8.3	----	9.8	7.4	9.6	10.2
Tracking									
Absolute Error (Hor.)	Mean	4432	4518	----	3890	5061**	4368	4449	4609
	S.D.	1026	1100	----	970	799	1096	1034	1048
RMS Error (Hor.)	Mean	70.9	73.4	----	64.0	80.3**	70.0	71.4	74.9
	S.D.	14.7	14.8	----	13.1	11.5	14.8	15.3	13.8
Absolute Error (Vert.)	Mean	4557	4525	----	4066	5016**	4336	4679	4608*
	S.D.	909	1048	----	952	754	1018	1028	854
RMS Error (Vert.)	Mean	73.9	75.2	----	67.7	81.3**	71.5	76.4	75.6
	S.D.	13.0	14.5	----	13.5	10.2	14.6	14.1	11.9
Absolute Error (Vector)	Mean	6519	6598	----	5730	7388**	6336	6626	6714
	S.D.	1339	1521	----	1356	947	1502	1476	1285
RMS Error (Vector)	Mean	99.2	101.7	----	89.8	111.1**	96.6	101.7	103.0*
	S.D.	18.2	19.57	----	17.8	13.2	19.9	19.8	16.4

* = Statistical significance at or below the .05 level.
** = Statistical significance at or below the .01 level.

TABLE XIX.

The Main Effects of Diet, Workload and Period for Individual Performance Measures in the Problem Solving Task

Problem Solving Task Measure		Diet		Workload			Test Period		
		Crash	Normal	Low	Medium	High	1	2	3
SOLUTION									
Mean Time/ Response (ms)	Mean	861	905	---	812	954**	867	918	865
	S.D.	156	218	---	131	214	137	230	190
Intrasubject S.D. of Time/ Response (ms)	Mean	1148	1225	----	772	1601	1110	1291	1158
	S.D.	601	684	---	374	590	531	714	662
Percent Nonredundant Response	Mean	96.5	96.1	---	96.4	96.2	96.9	95.5	96.4
	S.D.	2.6	3.0	---	2.9	2.7	2.4	3.4	2.3
CONFIRMATION									
Mean Time/ Response (ms)	Mean	1006	1041	----	899	1148	999	1077	994
	S.D.	218	337	---	184	331	238	335	263
Intrasubject S.D. of Time/ Response (ms)	Mean	1317	1326	----	868	1775**	1255	1390	1320
	S.D.	620	851	---	402	732	674	825	720
Percent Correct	Mean	83.3	81.6	----	85.9	79.1**	84.2	82.4	80.8*
	S.D.	9.6	9.6	----	8.8	9.2	9.2	8.8	10.5

* = Statistical significance at or below the .05 level.
** = Statistical significance at or below the .01 level.

The interaction of workload with test period was significant ($p < .05$) in the composite score data of the mental arithmetic and tracking tasks. Those interactions are shown in Tables XV and XVI. For both tasks, the difference in performance under different workload conditions decreased during successive periods of an experimental session. This was mainly due to performance in the low and medium workload intervals declining toward the lower, but more stable, level of performance under high workload.

Raw Score Data. Raw score data (means and standard deviations) on individual performance measures in each task are shown in Tables XVII, XVIII, and XIX as a function of the main effects of diet, workload and test period. These data show that in the monitoring of green lights and meters, and in mental arithmetic, the enhancement of performance by fasting was consistent in all measures. This effect was statistically significant in the case of intrasubject variability (standard deviation) of response latencies in all three tasks. The percentage of signals detected was also significantly higher in the case of monitoring of green lights. Nominal superiority of performance in the fasting condition also occurred, with few exceptions, in measures of performance on tracking and problem solving although these effects were small and not statistically significant.

Increasing workload consistently caused a decrease in performance in all tasks but monitoring of red lights. Measures on all tasks except meter monitoring and tracking typically show best performance in the first period, worst performance in the second period, and slight recovery in the third period. Measures of performance on meter monitoring and tracking typically show a steady decline in successive periods. These effects of workload were, in most cases, statistically significant. The effect of test period was significant only in raw score performance measures of arithmetic and tracking tasks, and in the confirmation phase of the problem solving task. Individual raw score performance measures again typically show best performance in the first period, a substantial decline in performance in the second period and partial recovery during the third test period.

DISCUSSION

The significantly lower T_{re} ($p < .05$) for subjects during the crash diet when compared to the normal diet is possibly indicative of a decrease in activity level. There was not a statistically significant difference between the beginning mean T_{re} for the two conditions. The initial mean values were 37.40°C for the crash diet and 37.31°C for the normal diet. Therefore, the lower T_{re} during the crash diet was not the result of a lower initial value for that condition. The possibility of a reduced activity level was supported by the HR data. Although statistical significance was not reached ($p = .069$), mean HR values were lower during the crash diet than during the normal diet for all three reporting periods. In one reported study (10), energy expenditure in fasting obese men was significantly reduced during fasting. The most marked decrement, from 2.8 to 2.2 kcal/kg/h, occurred with walking. In that study, however, the subjects were men with a mean weight excess of 89 percent and thus are not completely comparable to our population.

Although a major decrement in blood glucose to hypoglycemic levels (< 50 mg percent) is not ordinarily associated with a 24-h fast (21), the change in blood glucose was determined in the event of such a decrement which could adversely affect performance or other measurements in this study.

Although activity level appears to have been reduced during the crash-diet condition, subjects did not report any greater feeling of fatigue. Even the significantly lower serum glucose levels during the crash-diet condition apparently had no effects on the subjective feelings of fatigue.

The values for the urinary 17-ketogenic steroids produced the only important findings for the analyses made of the urine collected in this study. During the crash diet the values were much lower during the night sleep period than during the same period for the normal diet. Other reports (16,17) have indicated decreases in 17-ketosteroids. These studies did not, however, evaluate the reduction by periods within the day as did our study. Our reported reduction during the sleep period only, though, would result in a reduction of the 24-h output and is thus consistent with those studies.

The energy conservation pattern apparent in physiological responses to the crash diet may have both protected mental functions mediating complex performance in the MTPB and prevented abnormal subjective fatigue as revealed by the FCL. Indeed, performance was significantly better, statistically, in the crash-diet condition than in the normal-diet condition in three tasks--meters, green lights, and arithmetic. Performance was also nominally better in the crash-diet condition in the other tasks except red lights.

The beneficial effect of the crash diet was to reduce decrements in performance due to increasing workload in meters, green lights, and arithmetic in the medium and high workload conditions. There was no effect of diet on any task in the low workload condition. There was no interaction of the effects of diet with time during a session. The effects of crash diet were relatively constant in all three 42-min periods of a session.

The mechanism causing effects of diet is not clear, but may have involved a general arousal effect of hunger resulting in increased alertness in the crash-diet condition, or may have been due to decreased arousal in the normal-diet condition due to the meal prior to testing. Although performance was enhanced in the crash-diet condition in several tasks of this experiment, and the effects were consistent and statistically significant, it should be noted that their magnitude was small, less than one standard deviation, relative to both intersubject and intrasubject variability. Although the practical significance of these effects may be questionable, they definitely indicate that the crash diet caused no performance deficits in the present situation.

The lack of performance deficits in the crash-diet condition at the 12,500-ft simulated altitude in the present study contrasts with the findings of King et al. (18) that a perceptual-motor task, the Minnesota block placement test, was adversely affected after several hours of food deprivation at both ground level and an altitude of 15,000 to 17,000 ft. The lack of a similar deficit in the present study in the tracking task, also a perceptual-motor task, is unexplained. King et al. also found that both high protein and high carbohydrate meals produced performance superior to the no-meal condition. The latter finding conflicts with the results of Simonson et al. (23), who found that performance level on a demanding visual vigilance task was highest following a "standard" or high fat meal and lowest after a carbohydrate meal. Performance associated with no meal was intermediate. This interaction of type of meal with type of task should receive further attention.

Although the long-term effects of diet on altitude tolerance have received considerable attention in the literature (20), little attention has been given short-term dietary variations. The small number of prior studies of short-term food deprivation have typically dealt with deprivation periods up to 10 h (5,15,18,23). The present findings suggest that when a physiological energy conservation pattern is possible, deficits may not occur at fasting intervals up to at least 26 h.

Our findings suggest a need for additional investigations of the interactions of various dieting strategies and altitude exposure. Of particular interest are the possibly contributing effects of mental and physical fatigue and the effects of "refeeding" high carbohydrate meals after periods of fasting. The latter effect, known to produce sometimes drastic reductions in blood glucose levels shortly after a meal of carbohydrate, has not been studied in people during exposure to moderate hypoxia. Other factors that have not been evaluated with respect to diet and altitude are age and circadian cycle. It should also be pointed out that long-term dieting, which may produce effects entirely different from those of short fasts, has not been studied for possible effects on pilot proficiency.

In summary, we have found that 24 h of crash dieting did not adversely affect the performance of complex tasks by male pilot surrogates who were 5 to 15 percent overweight when they were tested under sedentary conditions while breathing oxygen/nitrogen mixtures equivalent to an altitude of 12,500 ft (3,810 m). Our results indicate that fasting subjects were better able to sustain performance in the face of an increasing workload. This finding should not be construed as a positive one, however. Other conditions (e.g., heavy physical workload or +Gz stress) which may be imposed on the airman during flight were not investigated in our study. These and other factors could offset any possible beneficial effects of fasting and should be studied before any but the most tentative conclusions can be made.

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