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THE EFFECTS OF HIGH AMBIENT TEMPERATURE ON SHORT-TERM MEMORY

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Foreword

This report was prepared in the Environmental Stress Branch, Training Research Division, Behavioral Sciences Laboratory, under Project No. 1710, "Training, Personnel, and Psychological Stress Aspects of Bioastronautics," Task No. 171002, "Performance Effects of Environmental Stress." Dr. Gordon A. Ekstrand served as project scientist and Dr. W. D. Chiles as task scientist. Background research was begun in September 1961. The experimental phase of the study was performed in May 1963.

The study was performed in cooperation with the Biothermal Branch, Physiology Division, Biophysics Laboratory, and the authors wish to express their appreciation to Mr. John F. Hall, Chief, Biothermal Branch, and to the members of his staff who supervised the chamber during the elevated temperature runs.

The subjects in the experiment were provided under Contract No. AF 33(657)-7863 with the University of Dayton. The authors are indebted to Dr. George K. Noland and his staff for their efforts to obtain subjects who would physically qualify and who also would be able to meet the schedules of the experiment. Part of the data reduction and analysis were done at the Behavior Research Laboratory, Antioch College, under Contract No. AF 33(657)-7362. We gratefully acknowledge the assistance of Mrs. Barbara P. Thomson in carrying out the data reduction and data analysis programs.

This technical report has been reviewed and is approved.

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Abstract

The present study was designed to determine whether or not an increase in ambient temperature impaired man's ability to recall aurally-presented messages, and whether impairment was greater for some types of messages than for others. On three separate days, 15 men were exposed for 1 hour in an all-weather chamber to each of three different effective temperatures (ET): 72°, 90°, and 95°F. During each day's session they were given five successive recall trials on each of six different messages. The men had to work continuously during each hour-long session. The results showed that average recall dropped significantly as environmental temperature was increased. The recall decrement between 90° and 95°F was statistically significant, but the drop in recall between 72° and 90°F was not significant. Messages of all types suffered approximately equal decrements under the high temperatures.

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SECTION I

Introduction

Experiments on the effects of elevated temperatures on human performance are relatively few in number and most of these deal with psychomotor performance (ref. 20). Certain mental functions, however, are as essential to the successful conduct of an aerospace mission as are psychomotor functions, and therefore they demand further research. Furthermore, many mental functions are impaired by thermal stress (ref. 19). One mental function of great practical importance is short-term memory for unanticipated information or unrehearsed actions that may be hastily issued to an operator under stressful conditions.

Several studies have shown performance decrements under high temperatures which indirectly implicate short-term memory. Blockley and Lyman (ref. 2) obtained an impairment in mental arithmetic under exposures of an hour or less to effective temperatures of 100.5°, 109°, and 114°F. Mackworth (ref. 10) found an increase in errors for receiving and recording morse code messages under a 3-hour exposure to effective temperatures (ET) of 87.5°, 92°, and 97°F. Receiving morse code and performance of mental arithmetic both depend heavily upon short-term memory. These experimental findings are further reinforced by clinical evidence that shows short-term memory is impaired under psychological stress (refs. 4, 5, 7, 9 and 13).

These various studies suggested that a direct test of the effects of heat stress on immediate memory might be fruitful. In making a direct test, however, it was considered desirable to determine whether different types of retention materials would be differently affected by high temperatures. Verbal materials were chosen which approximated to various degrees the meaningful sentences employed in everyday communications. The actual materials chosen consisted of various lists of words, all of which were 24 words in length. Some of these word-lists sounded just like an English sentence, other lists sounded something like a sentence, while still others sounded like a random selection of words from the dictionary. The methods by which this property of sentence similarity can be achieved are discussed in a number of articles (refs. 11, 12 and 16). The particular method employed here is described in Tulving and Patkau (ref. 16, pp. 84-85). The reason for choosing word-lists which approximate meaningful English sentences to various degrees was that it was expected that the less a word-list was like an English sentence the greater the recall decrement it would show under high temperatures.

A second property of the word-lists used here was that some of them contained only very common words, while other word-lists contained many uncommon words. The latter word-lists have been shown to be more difficult to remember. They should also show greater recall decrement under elevated temperatures than word-lists composed only of very common words. After reviewing alternative measures of this variable (see ref. 18), the Lorge Magazine Count (ref. 15) was chosen for this study as the best measure of how common a word is in the English language.

The wide range of properties composing the word-lists used in this experiment provided a number of ways for detecting any impairment of memory for verbal materials due to elevated temperatures. In addition, the word-lists provided the possibility of identifying those characteristics of a meaningful sentence which make it most susceptible to degraded recall under high temperatures (viz, frequency of usage or approximation-to-English sentence structure).

SECTION II

Procedure

SUBJECTS

A total of 18 subjects were tested in the experiment. They were all male student volunteers from the University of Dayton who were paid for their services. In addition, all the subjects had to qualify physically for exposure to high temperatures.

APPARATUS

The apparatus consisted of a tape recorder and a speaker over which the taped stimulus materials were presented. The experiment was conducted in the Aerospace Medical Research Laboratories All-Weather Chamber which is a room 20 ft square and 8 ft high. Ten classroom chairs with writing-arms were placed in two rows of five chairs each. Three subjects were placed in each row with an empty chair between each of them. Three different dry-bulb/wet-bulb readings were used, viz, 80/63, 110/82, and 120/88 degrees Fahrenheit. The wind velocity was kept at approximately 50 ft/min. These temperature, humidity and wind velocity combinations yielded effective temperatures of approximately 72°, 90°, and 95°F, respectively. Temperature was maintained nearly constant throughout the chamber, as verified by temperatures recorded at floor level, ceiling, and right and left walls, as well as by a record of the air temperature itself.

A large observation window enabled the experimenters to keep a log-book record of the subject's behavior at all times for both medical purposes and for purposes of interpreting the performance data.

STIMULUS MATERIALS

The stimulus materials consisted of three sets of word-lists. These were constructed so as to constitute equated sets of stimulus materials. They are designated Set A, Set B and Set C and are reproduced in Appendix I. Each set consisted of six different word-lists. Each list was 24 words in length. Any one word-list was a particular combination of two different variables: 1) absolute frequency of the words in English usage, and 2) order-of-approximation of the word-list to a meaningful, English sentence. Out of any set of six word-lists, three of them utilized only high frequency words (H), while the remaining three utilized an alternation of high and low frequency words (H-L). Within these H and H-L categories, each of the three word-lists represented a particular order-of-approximation to English sentence structure. One word-list was completely unordered, i.e., the words were drawn at random from a pool of words with the result that any successive pair of words were only related to one another by chance. This is designated as "1st order approximation to English." Another word-list was only partially ordered, i.e., any four successive words were semantically and syntactically related, but relations embracing more than four words were essentially chance relations. This is termed "5th order approximation to English." Finally, the last word-list in each category was completely ordered, i.e., all 24 words constituted a meaningful English sentence. This is simply termed "Text."

Set A word-lists were those constructed by Tulving and Patkau (ref. 16). Sets B and C were constructed by the authors so that they were equated with Set A in terms of frequency and order-of-approximation to English (see Appendix II).

EXPERIMENTAL DESIGN

The experiment was designed so as to counteract the effects of order (but not sequence) in taking the three temperature treatments. The design is shown in table 1. On the basis of ease in scheduling, subjects were assigned to one of three groups. Each group took the temperature treatments in a different order. The order was such that every temperature treatment appeared once in each session. The design originally called for N=8 in each order-of-treatments group, but prior to the experiment one subject failed a preliminary physical examination and four subjects failed to appear for the first experimental session. A sixth subject failed to appear for the second and

TABLE 1

Order of Administration of the Temperature Treatments and Word-Lists
(temperature – degrees F)

	SESSION 1 (°F)	SESSION 2 (°F)	SESSION 3 (°F)
GROUP I N=7	72	95	90
GROUP II N=5	90	72	95
GROUP III N=6	95	90	72
WORD-LIST	Set A	Set C	Set B

third sessions and so his data for the first session were dropped from the analysis. The number of subjects who actually took all temperature conditions was N=7, N=5, and N=6, for Groups I, II and III, respectively. However, since the analysis of variance used in this experiment required equal size groups, an independent researcher was asked to discard at random two subjects from Group I and one subject from Group III. This gave a final N=5 for all groups.

The three sets of word-lists were administered as shown at the bottom of table 1: Set A in Session 1, Set C in Session 2 and Set B in Session 3. Every set was thus administered under every temperature condition and to every group. Which set was to be administered in which session was assigned at random. The order in which the word-lists were administered within a session was counterbalanced so that over the experiment as a whole each type of word-list was equally represented over every 10-minute interval of the hour-long temperature sessions.

TEST SCHEDULE

All sessions lasted 1-hour, a duration set by a conservative tolerance limit for the most extreme temperature condition. A schedule was devised which enabled testing each group at the same hour on successive days. This schedule is shown in table 2. On every test day, subjects arrived as a group and were given a brief orientation to elicit their co-operation. They were dressed in T-shirts, shorts and shower-clogs, and then seated in the chamber. The experimenter instructed them in the use of the recording notebooks, and then gave a brief series of digit-span tests. These tests served as a familiarization phase for the subjects and gave them practice in using the note-

TABLE 2

*Schedule of Temperature Treatments**

	MON (°F)	TUES (°F)	WED (°F)	THURS (°F)	FRI (°F)
GROUP II	90	72	95		
GROUP I		72	95	90	
GROUP III			95	90	72

*Note: Each group was run at approximately the same hour each afternoon. Temperatures were allowed to stabilize each morning prior to the afternoon experimental runs.

books and in listening to instructions. Then the instructions for the main part of the experiment were played and, at 10 minutes after entry into the chamber, actual tests of recall of the word-lists began. Thus the main recall tests began after only 10 minutes of exposure to the temperature. Since physiological effects of exposure to elevated temperatures accumulate over a period of time, the early word-lists in any given session would not, of course, reveal the full effects of elevated temperatures on immediate recall. Although we anticipated that this feature of the design might make the experiment somewhat less sensitive, we decided to begin the testing prematurely rather than have to discard other features of the experiment in order to tailor it to the 1-hour maximum duration. Because the word-lists were presented in counterbalanced order, every word-list of a given type was administered for some groups during the early, middle, and late periods of the hour-long sessions.

Within every hour-long temperature run, each of the six word-lists composing a given set was repeated five times in succession. A 1-minute recall period followed each of these five trials. Subjects were instructed to begin each trial on a different page and to write down as many words as possible each time, regardless of the order in which they were heard. (The exact instructions given the subjects are reproduced in Appendix III.)

At the end of each session, the subjects were removed from the chamber. After showering and dressing, they filled out a brief questionnaire and were interviewed collectively about their reactions to the experiment.

Results

GRAPHIC ANALYSIS

The results are summarized graphically in figures 1, 2, and 3. Figure 1 shows the average number of words correctly recalled on each trial for the total group of 15 subjects who were exposed to the 3 temperature conditions. The figure shows systematic downward displacements of the acquisition curve with each successive increase in ambient temperature. For all trials combined, the average number of correctly recalled words was 13.8, 13.1, and 12.0 for 72°, 90°, and 95°F (ET). Thus, when the temperature is raised from 72° to 90°F the average drop in recall over all trials is about two-thirds of a word, and when the effective temperature is further raised to 95°F an additional drop in recall of slightly over one word occurs. Over all conditions an average loss of almost two words occurs as a function of increasing the ambient temperature from 72° to 95°F.

All three curves in figure 1 are roughly parallel. That is, under all temperature conditions subjects showed about an equal cumulative improvement in recall. This indicates that learning did not proceed at different rates under the different temperature conditions. Additional trials (up to and including five trials) might be expected to compensate for degraded recall under elevated temperatures so that the acquisition curves would converge. However, if there is any tendency present, it is a tendency for the curves to diverge, a fact which would mean less rather than more of an improvement in recall ability over successive trials for the higher temperatures. Unfortunately, only five trials were administered for each list. It remains a matter of speculation whether any significant divergence actually would appear on further trials. Ultimately, of course, the curves would converge if subjects achieved perfect recall under all three temperature conditions.

One of the primary features in the design of the present experiment was the selection of retention materials which varied widely in those characteristics which should affect ease of recall. We anticipated that both poorly-structured word-lists and word-lists containing low-frequency words would show greater recall decrement under high ambient temperatures than the word-lists which were well structured and contained only high-frequency words. This hypothesis was not supported in the present study. All word-lists appeared to be uniformly affected by the temperature treatments as is clearly shown in figures 2 and 3.

Figure 2 shows separately for the H and H-L word-lists the average number of words correctly recalled on successive trials under each temperature condition. The entire set of H word-list curves is higher than the set of H-L word-list curves, showing that the latter were, in fact, much more difficult to recall. But there is no evidence that recall for the H-L word-lists was degraded more by elevated temperatures than was recall for the H word-lists. Recall for both H and H-L word-lists appears to have suffered approximately equal decrements under successively higher temperatures at all stages of learning.

Figure 3 shows separately for the 1st order, 5th order, and Text word-lists the average number of correct words recalled on all five trials under each temperature condition. Almost everything stated about figure 2 can be repeated about figure 3. That is, the sets of curves for the three levels of order-of-approximation to English are fairly well separated, indicating that this characteristic of the word-lists definitely affected ease of recall. However, when temperature effects are compared across each set of curves, approximately equal recall decrements from elevated temperatures occur at all three levels of this variable. These graphic results, then, indicate that approximately equal recall decrements occurred due to the elevated temperatures regardless of the properties of the stimulus materials.

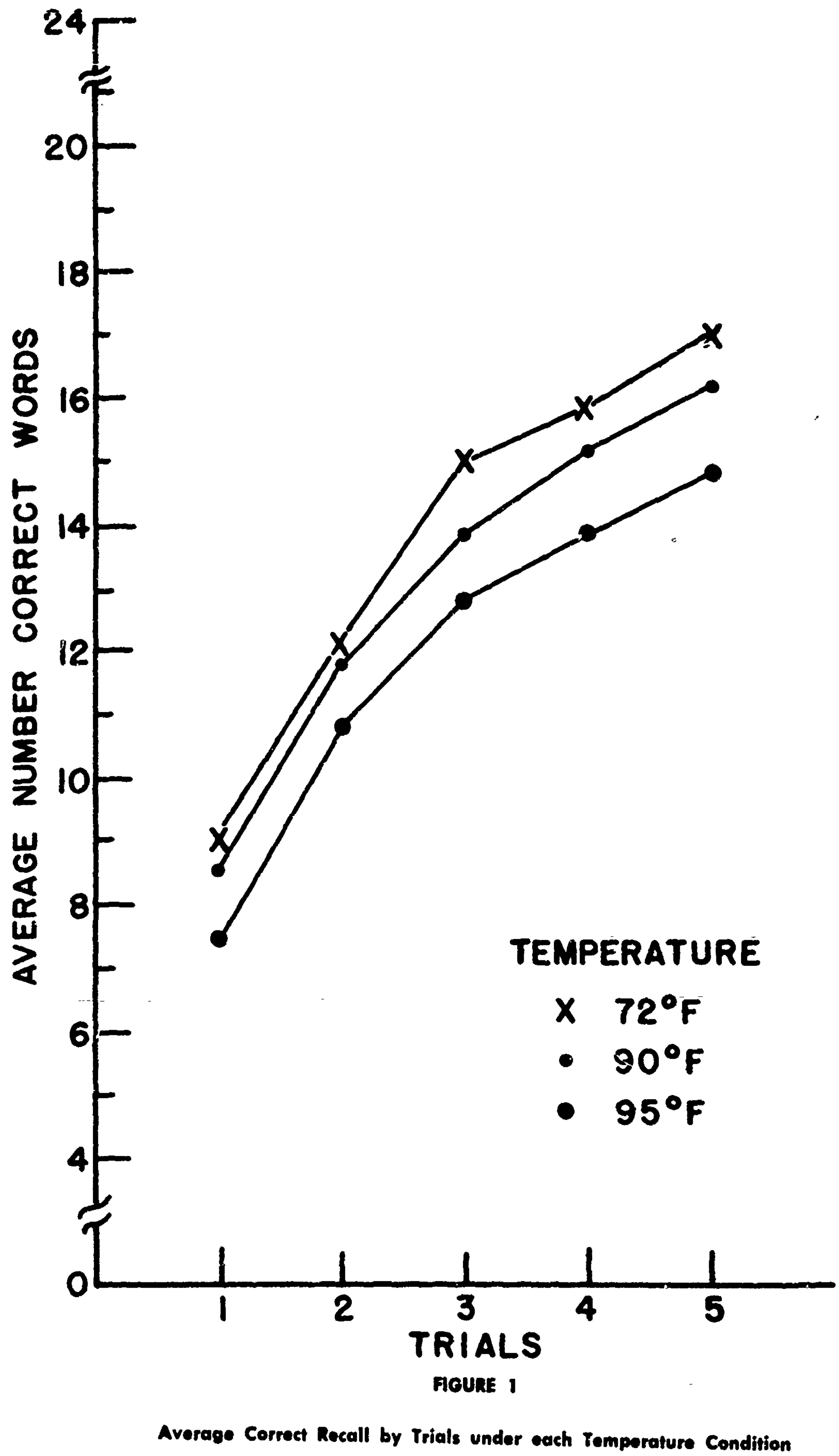

FIGURE 1

Average Correct Recall by Trials under each Temperature Condition

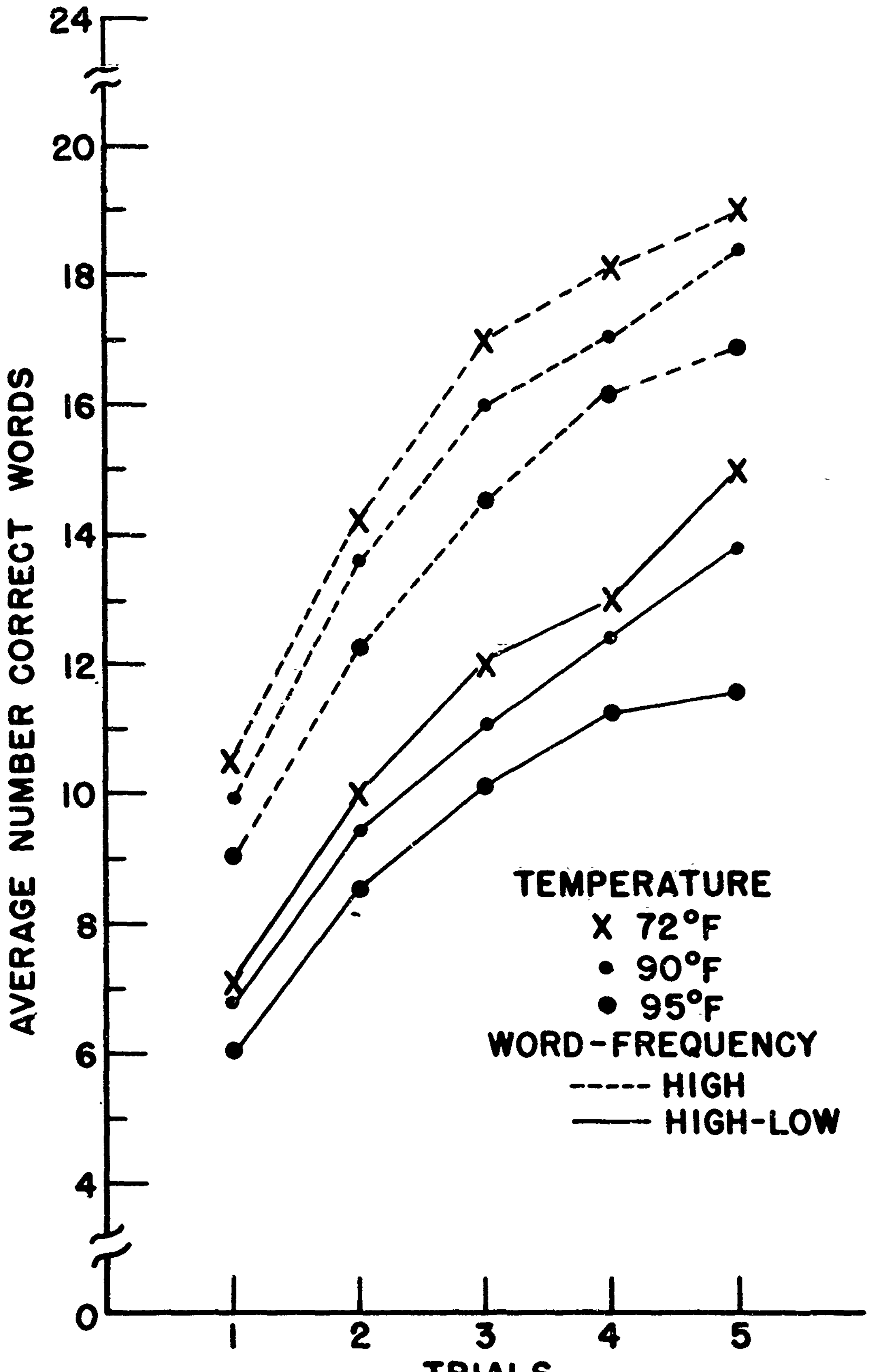

FIGURE 2

Comparison of Average Correct Recall by Trials under each Temperature Condition for Different Levels of Word Frequency

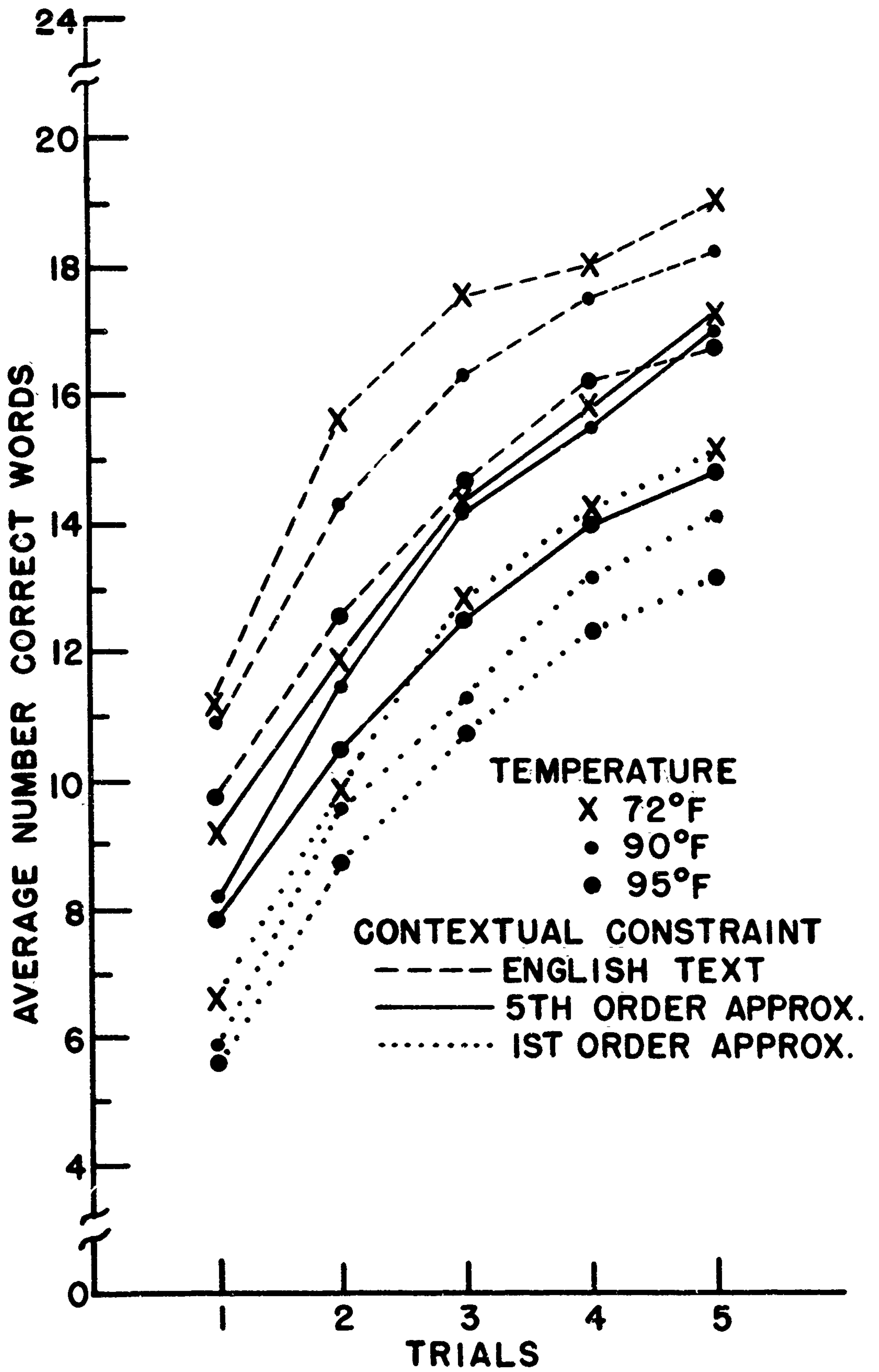

FIGURE 3

Comparison of Average Correct Recall by Trials under each Temperature Condition for Different Levels of Approximation-to-English

STATISTICAL ANALYSIS

An analysis of variance, which is summarized in table 3, was performed on the number of words correctly recalled. This analysis, an expansion of a Lindquist Type VII design (ref. 8, pp. 297-301), shows a number of statistically significant effects. The level of significance chosen for this study was $\alpha = .05$, and using this level the effects of temperature treatments was significant ($p < .005$). Because the overall effects of temperature were significant, t tests were applied to the differences between temperature means. The difference in mean error between 95° and 72°F and the difference in mean error between 95° and 90°F were both significant at $p < .05$. However, the difference in mean error between 90° and 72°F did not reach significance at this level. These tests indicate that a statistically-reliable impairment did not occur when the temperature was increased from 72° to 90°F effective temperature, but that a statistically-reliable impairment did occur with the increase from 90° to 95°F. Memory appears to be impaired at an effective temperature somewhere between 90° and 95°F.*

The analysis of variance also showed a number of other significant effects. The two properties of the word-lists which were systematically varied, frequency and approximation-to-English, also produced significant effects on recall ($p < .05$). In addition, learning was significant as revealed in the F value for trials (.001 level of significance). Although this main effect was significant, there were no significant interactions between trials and any other variables, including the trials by temperatures interaction. Thus the slight divergence noted in the acquisition curves of figure 1 is not statistically reliable, and we must conclude that learning rates did not differ under the three levels of temperature. These results of the analysis of variance confirm in every respect the conclusions reached in the graphic analysis.

The only other significant source of variance in table 3 is the interaction of frequency and approximation-to-English (the FA interaction). This significant interaction ($p > .05$) was also obtained in Tulving and Patkau's study (ref. 16, pp. 86-88) which utilized only Set A of the retention materials. The nature of the interaction in this study was exactly the same as it was in their study: approximation-to-English had a marked effect on recall in high frequency word-lists, but an almost negligible effect on recall in low frequency word-lists. However, this differential effect of approximation-to-English at each level of frequency was apparently the same under all temperature conditions as indicated by the nonsignificant triple interaction, TFA. This further confirms the finding that temperature-induced impairments in recall do not differ as a function of the specific properties of the word-lists.

Although the analysis of variance reveals a significant memory decrement under high temperatures, it does not show whether a large percentage of subjects showed a small decrement, or a small percentage of subjects showed a large decrement. To determine which of these conditions was true, a nonparametric L test (ref. 14) was applied to the data. This test determines whether a significant proportion of subjects performed according to a hypothetical rank-ordering of treatment effects. In this experiment, the predicted rank-ordering was 72°>90°>95°F with the highest recall (Rank 1) expected under 72°F and the lowest recall (Rank 3) expected under 95°F. Appendix IV gives the mean number of correctly recalled words for each subject under each temperature condition, the ranks based on these means, and the calculations on which the L statistic are based. The calculated L was 197.0. For three treatments ($n=3$) and fifteen subjects ($m=15$), this value of L has an exact probability of $p=.001$. We concluded that there exists a significant amount of agreement between the predicted ranking of the treatment effects and the

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*Comparable results are obtained using the nonparametric, Wilcoxon T-test for paired replicates (ref. 17). This test showed that the difference between 95° and 72°F was significant at $p < .005$; the difference between 95° and 90°F was significant at $p < .01$; but the difference between 90° and 72°F was not significant at the .05 level.

TABLE 3

Analysis of Variance of Number of Correctly Recalled Words†

Source	df	Sum of Squares	Mean Square	Error Term	F
TS (b)=G	2	898.70	449.35	error (b)	2.606
error (b)	12	2,069.30	172.44		
Temperatures=T	2	2,781.04	1,390.52	error 1	6.931*
Sessions =S	2	119.91	59.96	error 1	.299
Frequency =F	1	6,607.44	6,067.44	error 2	7.846*
Approx. to English =A	2	4,054.16	2,027.08	error 3	6.177*
Trials =t	4	10,523.10	2,630.78	error 4	8.959*
TS (w)	2	178.69	89.34	error 1	.445
TF	2	3.64	1.82	error 5	.004
TA	4	20.83	5.21	error 6	.024
Tt	8	47.99	6.00	error 7	.035
SF	2	25.80	12.90	error 5	.027
SA	4	193.99	48.50	error 6	.221
St	8	53.37	6.67	error 7	.039
FA	2	4,318.18	2,159.09	error 8	5.520*
Ft	4	111.65	27.91	error 9	.065
At	8	29.43	3.68	error 10	.018
TS (b) F=GF	2	37.65	18.82	error 2	.024
TS (w) F	2	40.67	20.34	error 5	.042
TS (b) A=GA	4	337.69	84.42	error 3	.257
TS (w) A	4	73.98	18.50	error 6	.084
TS (b) t=Gt	8	16.95	2.12	error 4	.007
TS (w) t	8	48.49	6.06	error 7	.038
TFA	4	33.77	8.44	error 11	.019
TFt	8	50.47	6.31	error 12	.025
TAt	16	57.36	3.58	error 13	.029
SFA	4	227.98	57.00	error 11	.129
SFt	8	89.44	11.18	error 12	.045
SAt	16	38.28	2.39	error 13	.020
FAt	8	75.06	9.38	error 14	.031
TS (b) FA=GFA	4	25.45	6.36	error 8	.030
TS (w) FA	4	116.02	29.00	error 11	.065
TS (b) Ft=GFt	8	27.80	3.48	error 9	.008
TS (w) Ft	8	42.71	5.34	error 12	.021
TS (b) At=GAt	16	74.88	4.68	error 10	.023
TS (w) At	16	60.07	3.75	error 13	.031
TFAt	16	38.19	2.39	error 15	.013
SFAt	16	44.65	2.79	error 15	.015
TS (b) FAt=GFAt	16	55.50	3.47	error 14	.011
TS (w) FAt	16	67.33	4.21	error 15	.022
error (1)	24	4,814.98	200.62		
error (2)	12	9,279.47	773.29		
error (3)	24	7,875.64	328.15		
error (4)	48	14,048.29	292.67		
error (5)	24	11,585.24	482.72		
error (6)	48	10,539.71	219.58		
error (7)	96	16,359.18	170.41		
error (8)	24	17,038.44	209.94		
error (9)	48	20,659.95	430.42		
error (10)	96	19,427.51	202.37		
error (11)	48	21,255.51	442.82		
error (12)	96	23,930.18	249.27		
error (13)	192	23,322.01	121.47		
error (14)	96	29,517.51	307.47		
error (15)	192	36,195.51	188.52		

†Note: Dr. H. Leon Harter, Senior Scientist in Mathematical Statistics at the Aerospace Research Laboratories derived the error terms for this expanded analysis. Before performing this analysis, visual inspection showed very slight departures of the data from the assumptions of normality and homogeneity of variance, except for trials and the interaction of trials with other factors. However, even the main effect of trials and those interactions involving trials did not show significant heterogeneity when tested with the Bartlett test (Lindquist, ref. 8, pp. 87-90).
*Significant at $\alpha=.05$ or better.

obtained rankings of performance. Due to the nature of the test, this indicates a large percentage of subjects must have approximated rather closely the predicted rank order.

Inspection of these ranks shows that 11 of the 15 subjects (73%) showed their poorest performance under the highest temperature condition (Rank 3). Eight of these (53%) had the exact rank order which was predicted, while three of them showed a reversal of the two lowest temperature conditions. The four subjects (27%) who produced the most discrepant rank-orders (subjects No. 2, 4, 7 and 12) actually showed little difference in performance under the three temperature conditions. These results show that about a quarter of the subjects either were not affected by high temperatures, or were able to compensate for the thermal stress, or else were poorly motivated under the lowest, control temperature.

Discussion

The main result of this experiment was the impairment in immediate memory under the highest temperature (95°F). The average difference in recall between the 72° and 95°F conditions was something less than two words. This represents about a 13% loss in performance. Furthermore, there is reason to assume that this is a conservative figure because testing began before subjects had received the full effects of thermal stress.

The findings of the present study are in essential agreement with results from two other experiments in which the effects of thermal stress on mental performance were assessed. Bartlett and Gronow (ref. 1) exposed subjects for a 1-hour period to effective temperatures of 72.5°, 82°, and 91.5°F. They tested the ability of subjects to estimate whether or not airplane silhouettes were moving along collision courses. On four different measures of performance, subjects showed no significant impairment under the temperature conditions.

Chiles (ref. 3) exposed subjects to 76°, 81°, 86° and 91°F effective temperature and measured their performance on a complex, mental task. The subjects had to visually compare sets of symbols on a moving loop with sets of symbols on a stationary display and report whether the sets were similar or different. Neither errors nor omissions were affected by temperatures in this range.

Both the Bartlett and Gronow study and the Chiles study agree in reporting no performance decrement for temperatures up to 91° or 91.5°F. In the present study a decrement in recall occurred with a rise in temperature from 72° to 90°F, but it was not statistically-reliable. Only the increase from 90° to 95°F proved to be significant. Thus all three studies place the impairment threshold (for a 1-hour exposure duration) at some value above 90°F effective temperature. The present experiment adds the additional information that the threshold for this particular task lies below 95°F effective temperature.

Although the basic results of this study are reasonable and are compatible with prior research, the secondary finding that recall is equally impaired for all kinds of word-lists is somewhat surprising. It had been reasoned that the subject's ability to recall word-lists with maximal efficiency would depend upon his utilization of all the cues or associations which tie the words together into a list. The cues which integrate sentence-like word-lists are all grammatical cues which activate well-rehearsed speech habits. These habits ought to be fairly resistant to stress effects. On the other hand, any cues which would tend to integrate word-lists with little or no sentence-like structure would all have to be supplied by the subject himself in the form of ephemeral, weak, indirect associations. These ought to be highly susceptible to stress effects. Therefore, we expected that the more highly-structured the word-list, the less impairment there would be. Following a similar argument, we expected that word-lists composed of very frequent words would provide stronger associations than word-lists which contained infrequent words; and thus the latter would also suffer greater stress effects.

The failure to obtain differential impairment in recall of these word-lists indicates the hypothesis was either incorrect or incomplete. There is reason to believe it was probably incomplete. Easterbrook (ref. 6) has suggested that stress degrades performance by narrowing the range of cues to which the subject responds. Both span of attention and memory span are so affected. However, Easterbrook also suggests that serial-motor and verbal tasks undergo a disintegration under stress, including syntactic speech (ref. 6, pp. 187-188). Thus, stress may have been operating on two different aspects of the subjects' performance in this experiment: their absolute spans of attention and of memory and also their serial-integration ability. Performance on highly-integrated word-lists may have suffered the effects of both factors, and this would have offset any potential advantage they might have seemed to possess.

There is also another explanation which could account for the failure to obtain differential impairment. The present design did not allow examination of performance at different points during the hour-long sessions. Differential impairment in recall for the different word-lists could have been developing over time, but the differences were only beginning to appear in the later stages of exposure. Further research should be done to determine the overall rate of impairment during the period of exposure and to find out if the individual rates for different word-lists begin to diverge toward the end of the period.

Appendix I

Three Sets of Word Lists

SET A

	HIGH FREQUENCY (H) WORD-LISTS			HIGH-LOW FREQUENCY (HL) WORD-LISTS		
	1st Order	*5th Order*	*Text*	*1st Order*	*5th Order*	*Text*
1.	realize	caught	five	said	good	he
2.	master	five	laughing	aft	edicts	derided
3.	future	wrong	children	family	lost	the
4.	in	people	built	gad	mysteriously	deportment
5.	use	soon	beautiful	mark	very	of
6.	middle	forget	large	dreamy	filthy	commodores
7.	until	character	ships	life	articles	whose
8.	step	differences	which	dishearten	accidentally	condescending
9.	promise	if	really	still	offered	manner
10.	left	school	sailed	hobble	relaxation	habitually
11.	bear	boards	so	fail	when	made
12.	born	fight	that	questionable	deplorable	considerate
13.	kitchen	teachers	they	sir	conditions	and
14.	cost	during	could	gratification	overshadow	punctual
15.	rock	real	play	second	a	people
16.	day	dollar	several	graphite	sophisticated	unhappily
17.	city	races	interesting	method	wife	more
18.	really	far	games	robust	unfamiliar	self-conscious
19.	fly	across	together	stay	to	than
20.	law	several	while	wisp	illiterate	patronizing
21.	instead	hard	their	set	women	words
22.	word	plains	fathers	gloss	scrutinizing	oftentimes
23.	wife	as	watched	each	the	spoken
24.	see	full	them	cannibal	linoleum	courteously

SET B

	HIGH FREQUENCY (H) WORD-LISTS			HIGH-LOW FREQUENCY (HL) WORD-LISTS		
	1st Order	*5th Order*	*Text*	*1st Order*	*5th Order*	*Text*
1.	continue	probably	then	wonder	human	people's
2.	upon	releasing	several	graphic	propaganda	agonizing
3.	action	near	eager	year	is	self
4.	dress	them	soldiers	ruinous	stigmatizing	appraisal
5.	system	my	lifted	smile	least	seems
6.	so	friends	some	cultural	frequently	decidedly
7.	yet	would	awkward	never	when	to
8.	locate	give	heavy	enhance	forlorn	eventuate
9.	foreign	parties	objects	carry	hearts	in
10.	itself	every	which	goodly	forsook	transformation
11.	present	possible	had	plant	present	of
12.	home	opportunity	fallen	orator	attachments	behavior
13.	power	comes	quite	going	in	but
14.	once	sometime	suddenly	appliance	exchange	terrifying
15.	month	when	from	peace	for	fatiguing
16.	he	you	their	repay	automatic	arduous
17.	follow	think	places	me	action	experiences

SET B—(continued)

	HIGH FREQUENCY (H) WORD-LISTS			HIGH-LOW FREQUENCY (HL) WORD-LISTS		
	1st Order	*5th Order*	*Text*	*1st Order*	*5th Order*	*Text*
18.	mean	tables	high	promontory	synchronized	invariably
19.	fall	most	above	receive	by	produce
20.	square	desirable	the	grandparent	narrowly	profound
21.	part	to	city	now	controlling	and
22.	mountain	obtain	roofs	privacy	limitations	permanent
23.	station	necessary	and	labor	slowly	character
24.	half	permits	towers	reinforce	applied	alterations

SET C

	HIGH FREQUENCY (H) WORD-LISTS			HIGH-LOW FREQUENCY (HL) WORD-LISTS		
	1st Order	*5th Order*	*Text*	*1st Order*	*5th Order*	*Text*
1.	shake	too	lots	held	adequate	legislators
2.	doctor	many	of	nosegay	attempts	instigated
3.	realize	great	men	name	made	businesslike
4.	is	gardens	wear	incurable	unexpectedly	investigations
5.	neither	now	bright	not	often	of
6.	usual	gave	silk	griddle	ugly	phenomena
7.	public	everything	shirts	find	instruments	whose
8.	paper	possible	which	survivor	energetically	outstanding
9.	of	since	certainly	either	seeking	qualities
10.	buy	uncle	shine	unrivaled	refinement	were
11.	business	has	in	help	when	consistently
12.	under	told	a	farcical	appropriate	manifested
13.	player	women	way	was	occasions	as
14.	toward	particular	that	sherbet	converge	outlandish
15.	that	street	suddenly	work	on	and
16.	various	fights	makes	sacrificial	domesticated	extravagant
17.	year	begin	human	came	chickens	displays
18.	so	in	beings	fallacious	unattended	designed
19.	happen	often	continue	character	by	to
20.	just	knowing	watching	jealously	articulate	consciously
21.	on	national	them	mother	speakers	offend
22.	unimportant	press	disappear	hamper	addressing	already
23.	money	probably	from	floor	a	aggravated
24.	help	couldn't	view	winsom	convocation	people

Appendix II

*Comparison of Word-Lists in Terms of Frequency of Usage**

HIGH (H) WORD-LISTS

	1st Order		5th Order		Text	
Set	Range H	Med. H	Range H	Med. H	Range H	Med. H
A	376 - 75,253	1,160	356 - 30,693	1,174	370 - 55,667	2,122
B	288 - 49,268	1,569	160 - 115,358	1,997	120 - 236,472	1,615
C	208 - 112,601	1,850	194 - 75,253	1,434	264 - 117,222	1,551
Average for All Lists	291 - 79,041	1,527	253 - 73,768	1,486	251 - 136,454	1,763

HIGH-LOW (HL) WORD-LISTS

	1st Order		5th Order		Text	
Set	Range H	Med. H	Range H	Med. H	Range H	Med. H
A	404 - 13,309	1,355	55 - 236,472	3,591	191 - 236,472	5,489
B	472 - 23,364	1,822	464 - 75,253	1,663	160 - 138,672	1,868
C	522 - 58,732	2,320	178 - 117,222	988	116 - 138,672	2,337
Average for All Lists	466 - 31,802	2,132	232 - 142,982	2,381	156 - 171,272	3,231
Set	Range L	Med. L	Range L	Med. L	Range L	Med. L
A	[illegible] - 37	19	7 - 53	28	9 - 58	16
B	5 - 67	22	4 - 256	33	1 - 105	39
C	2 - 42	18	2 - 127	16	3 - 100	30
Average for All Lists	3 - 49	20	4 - 145	26	4 - 88	28

*Lorge-Magazine Count (ref. 15).

Appendix III

Orientation and Instructions to Subjects

ORIENTATION

Each day you are run in the chamber, you will be subjected to a different temperature. On the days in which the temperature is quite high, a Doctor will be on duty. The temperatures are not so high that you will be in any physical danger, but it is only fair to warn you that you may feel physically taxed after certain of the sessions. If at any time you do not feel you can continue for some reason, you may raise your hand in the chamber and one of us will help you out of the chamber.

The kinds of tasks which we will be giving you require continuous effort and mental alertness. They will be memory tasks, and we expect your complete attention and maximum effort in giving your best performance under *all* the temperature conditions.

Are there any questions?

Now these memory tasks require your using these booklets. (E passes them out and instructs Ss in their use.)

INSTRUCTIONS FOR DIGIT-SPAN

Your first test will be an immediate memory test. I will read a series of numbers (and when I am done reading them a buzzer will sound). When it sounds, pick up your pencils and write the numbers down in the *reverse order* in which I read them to you. All ready?

3 - 2 - 7 - 9
Buzz!

Please turn your booklet to the next page. Now let's try a longer series.

INSTRUCTIONS FOR WORD-LISTS

The second test you will take is designed to see how well people can remember lists of English words. You will listen, without writing anything, to a list of words. Then, when the buzzer sounds, pick up your pencil and write as many words as you can remember, in any order in which you can remember them. You will hear this *same* list a second, third, fourth and fifth time and you will be asked to recall the list after each reading. Your final score on the list will be the total number of words recalled correctly on all five trials, so write down all the words you can recall each time the list is read.

Now I will read the first list for the first time. Listen carefully and write down the list when you hear the buzzer. All ready?

1st list – Trial 1
Buzz!
1 min. recall

Now, listen carefully once again and be prepared to write when the buzzer sounds.

1st list – Trial 2
Buzz!
1 min. recall

Appendix IV

Application of the L Statistic to Subject's Mean Recall Scores Rank-Ordered Across Temperature Conditions

	Subject No.:	Test Temperatures 72°F	90°F	95°F
	Predicted Ranking:	1	2	3
		Obtained Rankings:		
Group II n=5	1	1	2	3
	2	2	3	1
	3	2	1	3
	4	1	3	2
	5	1	2	3
Group I n=7	6*	1.5	3	1.5
	7	3	2	1
	8*	1	3	2
	9	2	1	3
	10	2	1	3
	11	2	1	3
	12	1	3	2
Group III n=6	13	1	2	3
	14*	1	2	3
	15	1	2	3
	16	1	2	3
	17	1	2	3
	18	1	2	3

$$\sum_{y}^{m} x_{ij} = 25.5 + 37.0 + 45.5 = 108.0$$

$$L = \sum_{y}^{m} y\, x_{ij} = (1 \times 25.5) + (2 \times 37.0) + (3 \times 45.5) = 236.0$$

The probability of obtaining an L of 236.0 or greater for n=3 and m=18 is .001. (The n in this experiment consists of the three temperature treatments; the m in this experiment consists of the 18 sets of ranks, one set for each subject.) For the complete rationale and the complete computational procedure behind the L test, see ref. 14.

*Note: These subjects' scores were omitted from the analysis of variance, in order to meet the requirements for equal-size treatment groups. Their scores are included in this analysis, however, since the entire sample of eighteen subjects can be utilized in making the L test.

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The present study was designed to determine whether or not an increase in ambient temperature impaired man's ability to recall aurally-presented messages, and whether impairment was greater for some types of messages than for others. On three separate days, 15 men were exposed for 1 hour in an all-weather chamber to each of three different effective temperatures (ET): 72°, 90°, and 95°F. During each day's session they were given five successive recall trials on each of six different messages. The men had to work continuously during each hour-long session. The results showed that average recall dropped significantly as environmental temperature was increased. The recall decrement between 90° and 95°F was statistically significant, but the drop in recall between 72° and 90°F was not significant. Messages of all types suffered approximately equal decrements under the high temperatures.

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Stress, physiology						
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