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THE EFFECT OF DIFFERENT TEMPERATURES AND RELATIVE HUMIDITIES ON THE RESISTANCE OF RATS TO A PNEUMOCOCCUS INFECTION

DISSERTATION

Submitted to the School of Hygiene and Public Health of the Johns Hopkins University in Conformity with the Requirements for the Degree of Doctor of Science in Hygiene

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INTRODUCTION

It has been stated by some observers that the moderately high temperatures and relative humidities which are present in the textile and allied industries produce physiological effects that are harmful. These conditions are said to "lower the resistance of the workers", making them more susceptible to any infection with which they come into contact. So far as I have been able to discover, this opinion has neither been proved nor disproved by any scientific investigations. In the hope of making a contribution on this point, the animal experiments reported in this paper were carried out.

Review of the Literature

In investigating the relation between resistance to infection, and external heat and moisture, two general methods have been used: Statistics and animal experimentation. Owing to the difficulty of separating the effects of temperature and humidity from those of many other variables, the results from statistics have not been conclusive.

Perry (1) has collected statistics showing that in the cotton weaving industry the death rate from all causes

and especially from tuberculosis is much higher among operatives than among non-operatives. He has shown further that among operatives the death rate is greatest in the spinning room and he suggests that this may be due to its "hot, damp, debilitating atmosphere."

Baker (2), in studying the relationship between the health of school children and methods of ventilation in class rooms, could discover no correlation between the per cent of absence and the relative humidity or saturation deficit. Her results indicate that a temperature of 59° F. is less favorable than one of 69° F.

Several investigators (Anders[3], Baker[4], Greenburg[5], Huntington[6]) have shown by the methods of statistics that the death rate from the respiratory diseases, especially pneumonia and influenza, is higher in winter than in the summer months. Anders found no relation between relative humidity and death rate. Huntington and Greenburg, on the other hand, found the death rate from pneumonia higher when the relative humidity was high than when it was low. Huntington believes that both a very high and very low relative humidity are unfavorable, especially when combined with high temperatures. These authors are divided in their opinion as to whether the high death rate from pneumonia in winter is due directly to climatic conditions or to the warm, dry conditions which prevail in houses and hospitals

during the winter months. Huntington says that "most of the harmful effects of cold weather are probably due to the injuriously low humidity in hospitals and houses." Anders concludes that "the major influence excited by the seasons is probably not direct but indirect, namely, by bringing about that effective element in the causation, concentration and increased virulence of the specific poison in consequence of closed doors and windows and lack of free ventilation."

I have been able to find very little experimental work on the effect of external temperatures on resistance and less on the effect of different relative humidities on resistance.

Filehne (7) infected the ears of several rabbits with an organism which brought about a condition very like erysipelas in man. After infection he exposed some of the animals to moderate warming by placing them in an incubator at 37°C.. These animals developed a less severe case of erysipelas than the controls which were kept in a room temperature.

Rolly and Meltzer (8) kept rabbits in a thermostat room at a temperature (93° F.) high enough to raise their body temperature to 104°F. Then they injected each rabbit at intervals with small doses of pneumococcus, staphylococcus,

or streptococcus cultures and found that the heated animals showed decided advantage over the non-heated ones, surviving doses which inevitably killed the control animals. Out of the two animals kept at the high temperature and given the various infections mentioned above, five lived and five died. The six control animals, kept at ordinary temperatures, all died.

Walther (15) found that rabbits kept in a room warm enough to raise their body temperatures to 105-106° F. showed an increased resistance toward a pneumococcus infection but that after removal from a warm room they showed no greater resistance than the control animals. Walther made five experiments and used only three animals in each experiment.

Similar experiments were carried out by Rovighi (21). Rabbits whose body temperature was raised by confinement in an incubator showed a greater resistance toward infections with anthrax bacilli, rabbit's septicaemia bacilli, and toward infections with human sputum than did control animals kept at ordinary temperatures. Rovighi, Walther, and Rolly and Meltzer, therefore, all conclude that a rise in body temperature is a protective mechanism against infection.

Loewy and Richter (9) and Engelhardt (16) reached

the same conclusion using a somewhat different experimental procedure. They raised the body temperature of rabbits by the use of the Sachs-Aronson operation, or "heat puncture." Loewy and Richter found that animals after such an operation were more resistant to infections with pneumococci, chicken cholera bacilli and hog erysipelas bacilli than were control animals with normal body temperatures. Engelhardt used intravenous and intraperitoneal injections of staphylococcus cultures and found that animals with an increased body temperature were more resistant to staphylococcus infections than were the control animals, and that the resistance was more pronounced when the organisms were injected intravenously than when they were injected intraperitoneally.

All the experimental work reviewed so far has been concerned with raising the body temperatures of the animals used. The results have been quite uniform in indicating that resistance to infection is increased by an artificial fever which is produced either by a high external temperature or by a Sachs-Aronson operation. The effects of moderately high external temperatures have also been studied, though not so extensively. I am acquainted with three investigations on this subject, all of which seem to indicate that a moderately high temperature lowers resistance to infection. The experiments reported in this paper have, however,

given a very different result for a temperature of 84°F. with a medium relative humidity.

Fermi and Salsano (17) found that keeping guinea pigs for several weeks at a temperature between 91°F. and 95° F. decreased their resistance to a strain of avian tubercle bacilli which was too low in virulence to produce a general infection in normal guinea pigs. Moreover, mice kept at the same external temperature for the same time showed many more tubercle bacilli of both the avian and human types in their glands than did the control animals. When a high humidity was combined with a high temperature the resistance of the animals was lowered to an even greater extent.

Ritzmann(18) kept white mice for weeks at a temperature of 95° F. and found that they showed an increased resistance to infections of streptococci and of tetanus spores. After injections with streptococci the heated animals died in from one-half to three and one-half days while the controls lived for from one and one-half to eight days. Out of ten heated animals injected with toxin free tetanus spores three died. All ten of the control animals lived. Injections of tetanus spores plus streptococci gave similar results. Ritzman also cites some experiments by Wyssokowitsch leading to the same conclusions.

The more recent experiments of Ruata (19) bearing on this subject are summarized in the following way in the Report of the New York State Commission on Ventilation:

"Ruata kept guinea pigs at a temperature of 30°C. (86° F.) with a relative humidity of 85-95 per cent. and injected them with doses of typhoid, paratyphoid, dysentery and colon bacilli and cholera spirilla which were not fatal for normal animals. All the guinea pigs thus treated died in from four to twenty-six hours, while, of control animals exposed to the heat alone, without injections, 30 percent. succumbed."

The experiments reported below in this paper differ from the above experiments with a moderately high temperature in two important respects: They make a comparison between high, medium, and low humidities when combined with a moderately high or a medium temperature, and secondly, they make use of a high temperature (82-85° F.) which does not interfere with the normal growth and activity of the animals used. Ruata kept his guinea pigs at 86° F. with a relative humidity of 85-95 percent. and found that 30 percent. of the animals died from exposure to the heat. The warm temperature room in the experiments reported in this paper had no such harmful effect upon the health of the animals. Not a single one of the one hundred and fifty

rats exposed to a high temperature died from an extraneous infection or failed to gain weight during the experimental period. The temperaturesused by Fermi and Salsano and by Ritzman were even higher - between 91° and 95° F. Such temperatures must have interfered with the normal growth of the animals. In connection with the experiments reported below, it was shown that rats would not grow normally at a temperature of 92° F. with a medium relative humidity. It is brought out, also, in the following experiments that the average body temperature of rats kept at 84° F. is nearly two degrees higher than the average body temperature of the same rats living in a temperate room. Certainly the rats, and probably the guinea pigs and rabbits, used in the experiments of Ritzman and of Fermi and Salsano had a body temperature considerably above the normal.

The New York State Commission on Ventilation (20) has reported some experiments which indicate that in rabbits the formation of hemolysins and to a slight extent the formation of agglutinins is delayed by an external temperature of 86° F. In writing of these experiments the Commission reports:

"We have found very definite evidence of the harmful influence of moderately high temperatures, particularly if followed by sudden exposure to low temperatures, in

promoting susceptibility to bacterial infection. We find that rabbits maintained at a temperature of 86° F. show a distinctly delayed formation of hemolysins and a slightly reduced agglutinative power, as compared with animals kept at 68° F."

The experimental results up to the present time indicate, in general, that preceding an infection an external temperature high enough to raise the body temperature of animals to 104° F. is favorable but that a lower external temperature (between 92° F. and 95° F.) is unfavorable. The experiments in this paper, on the other hand, indicate that a temperature of 82-85° F. with a medium relative humidity is a favorable environment for rats receiving an intraperitoneal injection of pneumococci.

EXPERIMENTAL METHODS

Various conditions of temperature and humidity were produced artificially. The resistance of rats, previously exposed to these conditions, was judged by their susceptibility to an infection with a pneumococcus culture.

Breeding stock for the experiments was secured from the Wistar Institute and was inbred in this laboratory for several generations before the experiments began. The rats were healthy and followed the normal growth curve for the Wistar Institute rats (10). They were fed daily in a uniform McCollum diet of the following mixture:

3 Parts oat meal
3 Parts whole wheat flour
3 Parts corn meal
1 Part flax-seed meal
Milk
Cabbage or lettuce once a week.

For each experiment two sets of rats were selected. Each group served as a control for the other. In the preliminary experiments it was found that even in our inbred stock some families were more resistant to the pneumococcus infection than others. It was necessary, therefore, to

divide each family, in order to make the groups comparable, putting half in one group and half in the other. In addition, care was taken to balance the groups in regard to sex and in regard to body weight. As far as possible, rats between $1\frac{1}{2}$ and $2\frac{1}{2}$ months old and weighing between 80 and 125 grams were selected. The following are typical rat groups used in an experiment:

Group A	Group B
Family I	
♂124 gms.	♂135 gms.
♂121 "	♀114 "
♂110 "	♂111 "
♀100 "	♀ 96 "
♂116 "	♂116 "
♂108 "	♂102 "
Family II	
♂ 91 "	♂101 "
♀ 88 "	♀ 91 "
♀ 88 "	♀ 89 "
105 "	105 "
Average Wgt.	Average Wgt.

During the whole experimental period each rat was kept in a separate cage.

Three rooms in which the temperature and humidity were regulated were available for the experiments. Two of these were brick vault rooms (10 ft. x 12 ft. x 10 ft.), designed to maintain a constant temperature and humidity. The other room was smaller (6 ft. x 5.5 ft. x 7 ft.) and

made of beaver board. Its temperature was kept fairly constant by a thermostat regulator connected up with an electric stove. As the relative humidity in the vault rooms was normally between 40 per cent. and 50 per cent. with a temperature of 66° F. to 70° F., they could not be used when a very low relative humidity was necessary. But whenever possible, the vault rooms were used. Usually the temperature did not vary more than two degrees during an experiment. In none of the rooms was there a perceptible air current. All three were kept dark except for about one hour daily when the rats were being fed and the cages were being cleaned.

The temperature in the rooms was raised by electric heaters and the moisture was increased by hanging pieces of wet cheese cloth in front of the heaters. The cloths were kept damp by water siphoned from a large tub above and sucked up from large pans on the floor. By this method the moisture in the air could be increased until there was a difference of only 4° between the wet and dry bulbs.

In the preliminary experiments a group of six growing rats were kept for a month in a vault room with a dry bulb temperature of 92° F. At the end of three weeks, four of the rats, though young enough to be growing rapidly,

had not gained in weight. Two of them succumbed to extraneous infections. The controls, kept at ordinary temperatures, gained weight normally and remained healthy. A second experiment gave similar results.

The temperature in the room was lowered to 84°F. At this temperature, even when the relative humidity was as high as 85 per cent., the rats gained weight as rapidly as the controls kept at a normal temperature. Sundstroem (11) found that growing rats brought into an artificially produced tropical climate (average B.B. 89° F., W.B. 82.2° F.) did not gain weight as rapidly as the controls at ordinary temperatures. No such retardation was noticeable during my three weeks' experimental period at a temperature of 84° F.

The temperatures to which the rats were exposed fall into two groups, the "high temperatures" being between 82.5° F. and 85.0° F. and the "medium temperatures" being between 66.5° F. and 73.5° F. The relative humidities fall into three groups as follows:

High relative humidity - 75% to 86%.

(There was never a difference of more than 4° F. between the wet and dry bulbs.)

Medium relative humidity - 44% to 72 %.

Low relative humidity - 25% to 29%

The experiments, therefore, make a comparison as regards relative humidity between a high (75% to 86%), a medium (44% to 72%), and a low (25% to 29%) relative humidity and as regards temperature between what may be called ordinary room temperatures, or medium temperatures, and a moderately high temperature, 82.5° F. to 85° F. Higher temperatures could not be used owing, as stated above, to the fact that at such temperatures the rats do not grow normally. The temperature becomes a directly unfavorable condition as regards the metabolic processes.

Type 1 pneumococcus was selected as a suitable organism for testing the resistance of the rats after they had been exposed for two weeks to known conditions of temperature and humidity. Oppenheimer and Spaeth (12) found this organism very satisfactory for testing the relation between fatigue and infection in rats. Eighteen-hour broth cultures of a virulent strain, diluted to the desired strength with sterile broth, were injected intraperitoneally. The culture used for injection was a transplant from a highly virulent stock culture. The stock culture was taken from the heart's blood of a rat which had died from a pneumococcus infection. Such a culture in blood broth could be kept on ice for a month with little or no perceptible change in virulence. Each month a new stock culture was made from an animal that died from pneu-

mococcus infection. The culture used for injection was, therefore, always the first transplant from a heart's blood culture.

Since the virulence of the cultures is liable to change from unknown causes, the matter of selecting the proper dose for injection offers serious practical difficulties. It is obvious that if the dose selected is too strong and all the animals die, or if too weak so that all live, no conclusion can be drawn. The work of several series of experiments was lost in this way. At each injection an effort was made to choose a dose which was too weak to kill all the animals and yet strong enough to kill the more susceptible ones. Two-tenths of a cc. of broth containing .00002 cc. of the original culture usually served this purpose. In a single experiment all the rats injected received .2 cc. of the same broth dilution. It seems reasonable to suppose, therefore, that the rats received infections of almost equal value.

As the infected rats died they were autopsied and a smear made from the heart's blood and from the pleural and peritoneal cavities. Not a single case failed to show large numbers of diplococci in all three smears. Occasionally, when a rat died a shorter or longer time than was usual after injection, the organism was recovered from the blood and identified in pure culture.

It is unfortunate that the experiments given below cannot be compared directly with each other. The rats used in the different experiments are not comparable as to size, age and inheritance. The culture is an even greater variable. Although great care was taken to use the same methods in handling the culture throughout the experiments, it was impossible to keep the virulence of the organism constant. In each single experiment, however, in which rats of the same family group were exposed to different temperatures and humidities, the conditions may be considered as strictly comparable as regards the virulence of the organisms injected and the age, average weights, and hereditary resistance of the animals used.

EXPERIMENTAL RESULTS

High and medium temperatures were combined with high, medium and low humidities in various ways and two different combinations were used in each experiment. In most cases a second experiment was made, repeating the conditions of the first. The experiments may be grouped in the following order:

(a) High T. and Medium H. compared with (Medium T.& High H. / Medium T.& Medium H. / Medium T.& Low H.

(b) High T. and High H. compared with (Medium T.& High H. / Medium T.& Medium H.

(c) High T. and Medium H. compared with High T. and High H.

(d) High T. and High H. compared with High T. and Low H.

(e) High T. and Medium H. compared with High T. and Low H.

The individual experiments are first recorded and discussed according to the above grouping. On pages 29 and 30 c posite tables are given showing the results of all the experiments. In addition, summarized results of the experiments are pictured graphically in Figures 2 to 6. In these diagrams each black rectangle above the line represents a rat that died from .00002 cc. of a virulent strain of type 1 pneumococcus. The susceptibility of the rats expressed as the reciprocal of the number of days survived $\left(\frac{1}{\text{days survived}}\right)$ is indicated by the height of the black columns. Each rectangle below the line represents a rat that survived indefi-

nitely an injection of .00002 cc. of a pneumococcus culture. In every case in which the dose proved fatal the rats died within seven days after injection. The average time before death was two days.

(a) The effect of high temperature and medium humidity compared with a medium temperature and a high, medium or low humidity.

Two experiments were made comparing the effects of a high temperature and medium humidity with a medium temperature and high humidity.

EXPERIMENT 20

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
82.5°F.	73.5°F.	72%	10	2	20%	30%
67.0°F.	63.0°F.	80%	10	5	50%	

EXPERIMENT 21

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.0°F.	72.0°F.	58%	8	5	62%	38%
66.5°F.	61.6°F.	75%	9	9	100%	

In experiment 20 only two out of ten animals kept in the warm room with medium humidity for two weeks before

injection died, while in the cool, humid room five out of the ten animals died. The death rate was, therefore, 30% higher in the temperate than in the warm room. In Experiment 21, all the animals in the temperate room died and three out of eight lived in the warm room, making a difference of 38% between the death rates in the two places. Experiments 20 and 21 indicate, therefore, that a high temperature and medium humidity is a more favorable condition than a medium temperature and high humidity.

The combined results of the two experiments are shown diagramatically on page 60,Figure 2, and complete data for each experiment are given in Tables 1 and 2, pages 49 and 50.

Two experiments were made comparing the effects of high temperature and medium humidity with medium temperature and medium humidity.

EXPERIMENT 25

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
82.5°F.	75.5°F.	72%	9	7	78%	22%
68.0°F.	56.0°F.	46%	8	8	100%	

EXPERIMENT 26

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.5°F.	74.5°F.	66%	9	3	33%	11%
67.5°F.	56.5°F.	49%	9	4	44%	

In both rooms in Experiment 25 and in Experiment 26 the humidity was "medium" but the temperature was high in one case and medium in the other. In Experiment 25 all of the eight animals in the temperate room died after injection, while two out of nine lived in the warm room. It is probable that the difference between the death rates in the two rooms would have been greater if the pneumococcus dose had not been so heavy. Complete data for the experiment are given in Table 3.

In Experiment 26, six out of the nine animals injected in the warm room lived and only five out of the nine injected in the cool room lived. Complete data for this experiment is given in Table 4. The combined results of Experiments 25 and 26 are shown in Figure 6.

Two experiments were made comparing the effect of a high temperature and medium humidity with a medium temperature and low humidity.

EXPERIMENT 12

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.5°F.	69.5°F.	49%	6	0	0%	33%
73.5°F.	55.7°F.	29%	6	2	33%	

EXPERIMENT 11

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.5°F.	69.5°F.	49%	6	4	66%	17%
73.5°F.	55.7°F.	29%	6	5	83%	

Experiments 11 and 12 indicate that a high temperature with a medium humidity is a more favorable environment than a medium temperature with a low humidity. Since the experimental conditions were the same in both experiments, the results may be considered together. Out of twelve rats injected after living for two weeks in the warm room, four died and eight lived, and out of the twelve kept at a medium temperature seven died and five lived, making a difference of 25% between the death rates in the two places. Complete data for experiments 11 and 12 are given in Table 5, page 53.

The experiments reported so far, therefore, all point to the conclusion that rats are more resistant to a pneumococcus infection when they have been living at a high temperature with a medium humidity than when they have been living at a medium temperature.

(b) The effect of a high temperature and high humidity compared with a medium temperature and a high or medium humidity.

Two experiments were made comparing the effects of a high temperature and high humidity with a medium temperature and a high humidity.

EXPERIMENT 19

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.5°F.	79.5°F.	84%	11	4	36%	0%
71.0°F.	68.0°F.	81%	11	4	36%	

EXPERIMENT 14:

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
84.0°F.	80.0°F.	84%	7	6	86%	14%
70.0°F.	66.0°F.	81%	7	7	100%	

In Experiment 19 the two rooms compared differed only in temperature. The humidity was "high" in both places. Eleven rats were injected in each room, and out of each group four died and seven lived. Consequently, there was no difference between the death rates in the two rooms. The experiment indicates that a high temperature with a high humidity compares neither favorably nor unfavorably with a medium temperature and high humidity.

Complete data for Experiment 19 are given in Table 6, page 54, and the results are pictures in the bar diagram, Figure 3, page 61.

In Experiment 14a only one rat survived out of the fourteen injected. The dose of pneumococcus was evidently too heavy. The experiment is valueless and is included only for the sake of completeness.

Two experiments were made comparing the effects of a high temperature and high humidity with a medium temperature and medium humidity.

EXPERIMENT 16

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.5°F.	79.5°F.	84%	5	4	80%	0%
69.0°F.	59.0°F.	55%	5	4	80%	

EXPERIMENT 14b

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
84.0°F.	80.0°F.	84%	8	6	75%	5%
72.5°F.	63.5°F.	59%	5	4	80%	

In both of the above experiments the number of animals used was small. In three of the four groups only one animal survived out of the five injected. However, the experiments contribute some evidence that a high temperature with a high humidity is neither more nor less favorable than a medium temperature. Experiment 19, page 54, is a better experiment supporting the same conclusion.

Complete data for Experiments 16 and 14b are given in Table 7, page 55.

(c) The effect of a high temperature and medium humidity compared with a high temperature and high humidity.

The experiments in Section (a) show that a high temperature with a medium humidity is a favorable environment when compared with a medium temperature. Those in Section (b) show that a high temperature with a high humidity is neither favorable nor unfavorable when compared with a medium temperature. These two sets of experiments, therefore, give indirect evidence that at a high temperature humidity is a determining factor, a high humidity being less favorable than a medium humidity. Direct evidence for this statement is given by Experiment 17.

EXPERIMENT 17

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
84.0°F.	68.5°F.	44%	10	3	30%	30%
83.5°F.	79.5°F.	84%	10	6	60%	

In Experiment 17 six out of the ten animals injected in the warm, humid room died, while only three out of ten died in the room with medium humidity, making a difference of 30% between the death rates in the two places.

Complete data for Experiment 17 are given in Table 8, page 56, and the results are shown in the bar diagram, Fig-

ure 4, page 62.

(d) The effect of high temperature and high humidity compared with high temperature and low humidity.

The following two experiments were carried out to find out whether a high temperature is favorable or unfavorable when combined with a very low humidity.

EXPERIMENT 23

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.0°F.	79.0°F.	84%	8	4	50%	0 %
85.0°F.	62.5°F.	25%	8	4	50%	

EXPERIMENT 24
6

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.0°F.	79.0°F.	84%	10	9	90%	8%
85.0°F.	62.5°F.	25%	11	9	82%	

In Experiment 23 eight animals were injected in the warm room with low humidity and eight in the warm room with high humidity. In each room half of the animals injected died and half lived. In Experiment 24 nine out of ten animals died in the humid room and nine out of eleven died in the dry room. The two experiments, therefore, indicate that a warm, dry room is as unfavorable an environment as is a warm, humid room. This conclusion has not, however,

been supported by Experiment 22, which is discussed in Section (e).

Complete data for Experiments 23 and 24 are given in Tables 10 and 11 and the combined results of the two experiments are shown in Figure 3, page 61.

(e) The effect of high temperature and medium humidity compared with high temperature and low humidity.

It might be predicted from the results in the preceding experiments that a high temperature and low humidity is a less favorable condition than a high temperature and medium humidity. Experiment 22 was made in order to obtain direct evidence for or against this statement.

EXPERIMENT 22

D.B.	W.B.	R.H.	Number of Animals Used	Number of Animals Died	Mortality	Differences Between Death Rates in the Two Rooms
83.0°F.	73.0°F.	62%	11	8	73%	9%
85.0°F.	62.5°F.	25%	11	9	82%	

In experiment 22 eleven animals were injected in the warm room with medium humidity and eleven in the warm room with low humidity. In the former room eight out of the eleven animals died and in the latter room nine out of eleven died. There was a difference of only 9% between the death rates in the two rooms.

Complete data for this experiment are given in Table 9, page 57.

It is difficult to explain the apparent disagreement between the results obtained in Experiment 22 and those obtained in Experiments 23 and 24. Whenever a very low humidity was needed it was impossible to use the vault rooms. It was necessary, therefore, to use the small beaver board room in which the temperature and humidity were not so carefully controlled as in the vault rooms. Whereas, the temperature never fell below 83.0°F., it often rose for a short time as high as 90.0°F. This variation in temperature may be partly responsible for the inconsistent results obtained in Experiments 22, 23, and 24. One has the impression, after studying the three experiments, that a high temperature and low humidity is probably unfavorable when compared with the optimum condition - a high temperature and medium humidity, but that it is more favorable than either a medium temperature or a high temperature and high humidity.

SUMMARY OF RESULTS

The results of the experiments are summarized in the tables on pages 29 and 30. Those experiments in which a high temperature with a medium humidity is compared with some other combination of temperature and humidity are grouped in Table I. All the other experiments are included in Table II. The last column in the tables gives the differences between the death rates in the two rooms compared in a single experiment.

Experiments 20, 21, 12, 11, 25 and 26, all included in Table I, show that a high temperature with a medium humidity is a more favorable environment than a medium temperature with any relative humidity from 29% to 80%. In each experiment the death rate is higher in the temperate room than in the warm room, and in all but three cases it is 30% greater in the former than in the latter room. One of these exceptions (Experiment 25) would probably have shown a greater difference in death rates if the dose of pneumococcus had not been so heavy. Unfortunately, all the animals in the temperate room died after injection and only two survived in the warm room, making a difference of 22% between the death rates in the two places.

Experiment 17 indicates that a high temperature combined with a medium humidity is a more favorable condi-

TABLE I

TABLE INCLUDING ALL EXPERIMENTS COMPARING HIGH TEMPERATURE AND MEDIUM HUMIDITY WITH SOME OTHER SET OF EXPERIMENTAL CONDITIONS

Number of Experiment	Temperature	Humidity	Number of Animals Used	Mortality	Difference in Death Rates
17	High	Medium	10	30%	30%
	High	High	10	60%	
20	High	Medium	10	20%	30%
	Medium	High	10	50%	
21	High	Medium	8	62%	38%
	Medium	High	9	100%	
12	High	Medium	6	0%	33%
	Medium	Low	6	33%	
11	High	Medium	6	66%	17%
	Medium	Low	6	83%	
25	High	Medium	9	78%	22%
	Medium	Medium	8	100%	
26	High	Medium	9	33%	11%
	Medium	Medium	9	44%	
22	High	Medium	11	73%	9%
	High	Low	11	82	

TABLE II

TABLE INCLUDING ALL EXPERIMENTS EXCEPT THOSE IN WHICH A HIGH TEMPERATURE WITH A MEDIUM HUMIDITY WAS USED

Number of Experiment	Temperature	Humidity	Number of Animals Used	Mortality	Difference in Death Rates
19	High	High	11	36%	0%
	Medium	High	11	36%	
16	High	High	5	80%	0%
	Medium	Medium	5	80%	
14b	High	High	8	75%	5%
	Medium	Medium	5	80%	
14a	High	High	7	86%	14%
	Medium	High	7	100%	
23	High	High	8	50%	0%
	High	Low	8	50%	
24	High	High	10	90%	8%
	High	Low	11	82%	

tion than a high temperature with a high humidity, the difference between the death rates in the two places being 30%.

The small difference in death rates in Experiment 22 suggests that a high temperature and low humidity is almost if not quite as favorable a condition as a high temperature with a medium humidity. But other experiments have not supported this conclusion. Experiments 23 and 24 indicate that with a high temperature a low humidity is as unfavorable a condition as a high humidity. Nevertheless, one has the impression after studying all the experiments that a high temperature with a low humidity, though unfavorable when compared with the optimum conditions for resistance, is not so unfavorable as a medium temperature or as a high temperature with a high humidity. More experiments are needed to prove or disprove this point.

None of the experiments in Table II shows any significant differences in death rates. The highest difference shown is 14%, and this occurred in No. 14a. As was explained above, this experiment was unsatisfactory since the dose of pneumococcus was too heavy and thirteen out of the fourteen animals injected died. The experiments in Table II indicate that a medium temperature with a high, medium or low humidity, and a high temperature with

a high humidity are equally unfavorable conditions when compared with the optimum conditions - a high temperature and medium humidity.

THE EFFECT OF EXTERNAL TEMPERATURE ON THE BODY TEMPERATURE OF RATS

Rolly and Meltzer (8) and Loewy (9) showed that animals kept at febrile temperatures were able to develop a more effective mechanism for defence against various infections than were control animals kept at ordinary temperatures. They found further that agglutinins and bacteriolytic substances were produced far more quickly and in much greater amounts in the heated than in the unheated animals. In view of these results it seemed desirable to know what effect the moderately high temperatures and relative humidities used in the above experiments had upon the body temperature of the animals. A rise in body temperature might offer a partial explanation for the protective influence of an external temperature of 84° F.

Experimental Procedure

The rectal temperatures of four rats were taken daily over a period of five months. After the first two or three weeks the rats made no objection to the procedure. If handled properly, they would sit quietly in the palm of the hand for several minutes while the temperature was being taken. The average temperatures during the first two weeks were much higher than at any time later. On

some days in this period, when the rats were especially nervous, their temperatures rose as high as 102° F. Subsequently, as a result of the training, the animals were less excited and their average temperatures fell to a lower level and showed less variation. In the averages given below the temperatures observed during the training period of two weeks are not included.

After their initial training the animals were exposed to known temperatures and humidities for periods of two weeks for each combination used, and their rectal temperatures were taken once daily. The same certified thermometer was used for all the observations made.

Experimental Results

Observations were made during eight periods of two weeks each and seven different combinations of temperature and humidity were used. Five sets of observations were made at a high temperature and three at a low temperature. Between each high temperature period the rats were kept for two weeks or, in one case, for three days in the medium temperature room.

The results of the experiments are given in the following table (page 35) in which the averages are calculated from the fourteen daily observations on each animal recorded for each period. The maximum and minimum temperatures shown by the individual rats during each

THE MINIMUM, MAXIMUM AND AVERAGE BODY TEMPERATURE OF FOUR RATS
EXPOSED TO VARIOUS CONDITIONS OF TEMPERATURE & HUMIDITY
The exposure to each condition was for a period of two weeks

Periods	Average Room Temperature and Humidity			Body Temperature in Degrees Fahrenheit												Average for all Four Rats
				Rat 123			Rat 145			Rat 400			Rat 139			
	D.B. °F	W.B. °F	R.H. %	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	
I	82.0	79.0	84	95.7	99.5		96.0	98.9		95.8	100.1		95.8	99.5		
II	83.5	75.5	70	96.3	100.4		96.2	100.0		97.3	100.8		97.4	101.8		
III	83.0	72.0	58	96.2	98.9		96.2	101.2		97.0	101.1		96.5	100.7		
IV	85.0	63.0	25	97.2	99.7		97.0	99.9		96.0	100.3		96.3	100.0		
V	85.0	63.0	25	95.7	100.4		96.6	99.3		97.5	99.9		95.5	100.5		
VI	70.0	62.0	58	94.9	97.6		93.5	98.6		93.5	98.1		94.4	97.7		
VII	68.0	56.0	46	94.3	98.0		95.2	97.7		94.9	97.6		94.6	98.1		
VIII	66.5	59.0	54	95.3	97.6		94.6	98.4		94.0	100.0		95.6	100.7	*	

*Rat 139 gave birth to a litter of young on the second day of this experimental period. The average temperature is high owing to the excitability of the mother when taken away from her young each day to have her temperature taken.

period are also recorded.

The second, third and fourth columns in the table give the average external temperature and the average relative humidity during each period. Changes in the dry or wet bulb readings during any single experiment were small, never exceeding a variation of two degrees above or below the average.

All the rats, under all the conditions tried, showed a surprisingly wide range of body temperatures. A rat which on one day had a rectal temperature of less than 96°F. might on the next day show a temperature of over 100° F. There was no apparent reason for these wide fluctuations in body temperature. After the first two weeks the rats rarely objected to being handled. They were seldom even restless. On the few occasions when they did seem excited the thermometer readings were always high, sometimes above 101° F.

The second point brought out by the experiments was that the body temperatures of the rats varied with the room temperature. In every case the average readings from the rats living in the warm room were from one and a half to two and a half degrees higher than the average body temperatures of the same rats while living under temperate conditions.

The entire range of temperatures exhibited by the four rats exposed to a medium temperature (black diagram) and to a high temperature (red diagram) are shown in Figure I, page 38. The mean in the black diagram is 96.3° F. and in the red diagram it is 98.1° F. There is a difference of 1.8° F., therefore, between the mean body temperature of the four rats living at 66-70° F. and the mean body temperature of the same four rats living at a higher temperature (83-85° F.).

While the external temperature remained constant, changes in the relative humidity seemed to have no effect on body temperature. In periods 1, 2, 3, 4, and 5 in the table, the room temperature was practically the same but the relative humidity varied in the different periods from 25% to 84%. In spite of this variation, the average body temperatures during these periods showed no significant differences.

Conclusions

(1) The body temperature of rats is extremely variable, ranging from 94° F. to 101° F. under what seem to be normal conditions.

(2) The body temperature of rats varies with the external temperature, the average temperature at 68° F. being about one and eight-tenths degrees below the average body temperature at 83° F.

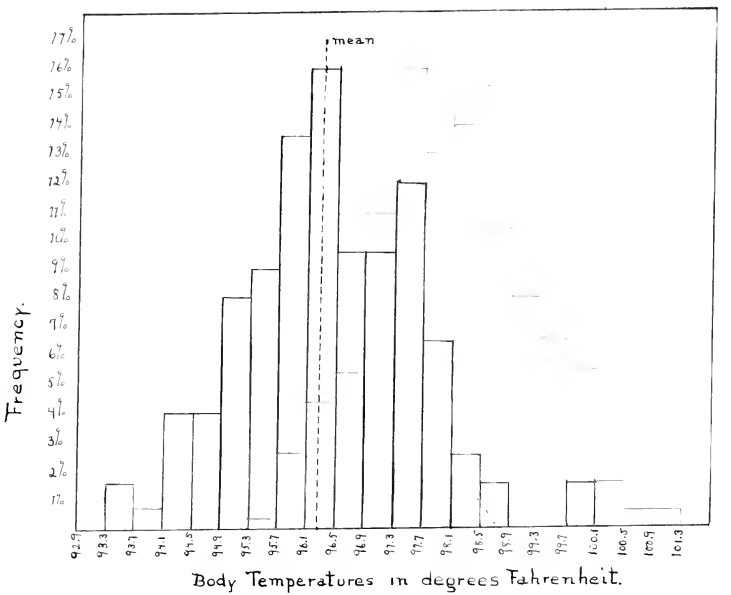

FIGURE I

Diagrams showing the entire range of body temperatures exhibited by four rats exposed to a high temperature - 82°F. to 84° F. - for a period of ten weeks (red diagram) and to a medium temperature - 66° F. to 72° F. - for a period of six weeks (black diagram).

The body temperatures are given along the abcissa. The ordinates express the frequency with which each body temperature occurred in terms of the percentage of the total number of observations.

(3) Variations in relative humidity between 25% and 84% had no noticeable effect upon the body temperature.

In this last respect the rat seems to differ from man since the observations of Houghton and Jaglo-glou (22) and of McConnell and Houghton (23) show that a high humidity combined with a high temperature is more effective in raising the body temperature than a high temperature plus low humidity. We should expect a similar result upon rats since the high humidity interferes with the physical regulation of body temperature by diminishing the heat loss from evaporation. In the case of the rat we have no knowledge of its means of heat regulation. The regulation is obviously imperfect as is indicated by the individual variations in body temperature when external conditions are kept constant. But from the above result it would seem that heat loss from evaporation plays an insignificant role in heat regulation in this animal.

DISCUSSION

It seems evident from the experiments recorded above that exposure for two weeks in a warm room with a relative humidity between 44% and 72%, increased the resistance of rats to an infection. Just how this increased resistance is brought about is not indicated in the experiments, but we may assume that in some way these special conditions strengthen the defensive mechanisms of the body.

In considering these mechanisms one thinks first, perhaps, of the phagocytic cells. It is possible that the high temperatures may have caused an increase either in the number or in the activity of the body phagocytes. The work of Murphy and Sturm (13) has shown that when rats are kept as a high dry temperature (55° F. -65° F.) for five minutes, there is a rapid fall in the number of both the polymorphic and mononuclear cells, followed subsequently, after transfer back to a normal environment, by an increase far above the normal count. But no such effect has been discovered in animals kept at moderately high temperatures. Sundstroem (11) found that mice kept for months in an artificially produced tropical climate (D.B. 89.2°F., W.B. 83.2° F.) showed a gradual but not very marked decrease in their total leucocyte count. The average for the

control animals was 7300, while that for the immigrants, after several months' residence in the tropical room, was 6880.

In connection with the experiments reported in this paper, blood counts were made on six rats which had been kept in the warm vault for two weeks, and on an equal number of control rats kept at room temperature. The tips of the rats' tails were cut off and several blood smears were made. In addition, two white and two red blood counts were made from each rat. The results were not entirely satisfactory but they were sufficient to show that there was no striking variation from the normal either in the total or in the differential counts of the rats kept in the warm room. Consideration of these results and of those of Sundstroem make very improbable the suggestion that the number of phagocytes increased during the two weeks' residence in the warm room.

There is some evidence that the activity of phagocytic cells increases with a rise of temperature. Rolly (14) showed this in vitro by using human washed corpuscles to which equal quantities of an emulsion of bacteria and of serum were added. The bacteria used were streptococcus, typhoid bacillus, staphylococcus, and tubercle bacillus. The mixtures were kept for fifteen minutes at various temperatures, ranging from $6^{\circ}C.$ to $51^{\circ}C.$, and then the bacteria

present in one hundred leucocytes were counted. It was found that the number of bacteria increased steadily up to 40° C. but that above 40° they began to fall off rapidly. Forty degrees was therefore the optimum temperature for phagocytosis by human corpuscles. If rats' corpuscles behave in a similar manner, the higher body temperature which the rats have while living in the warm room might be supposed to favor phagocytosis.

Rolly and Meltzer (8) have shown that in rabbits heated so that their body temperature is raised to about 40° C., agglutinins and bacteriolytic substances are produced in greater quantities than in control animals kept at room temperatures. They have not attempted to demonstrate differences in the quantities of these substances present through a lower range of body temperatures. It may be possible that these substances increase gradually with a rise in body temperature.

However, explanations of an increased resistance which are based on a rise in body temperature do not sufficiently explain the results obtained in the foregoing experiments. A rise in body temperature was obtained whenever the rats were placed in a high temperature room, whether the humidity was high or low, whereas the increased resistance was observed only when a medium humidity was com-

bined with the high temperature. One is justified, therefore, in concluding that the rise in body temperature which occurs in the warm room is not in itself sufficient to explain the increased resistance. The matter is more complicated than that. It is not profitable to go beyond this negative statement and speculate upon other possible reactions which may have occurred, and which directly or indirectly may have influenced the efficiency of the defensive mechanisms, since direct data are lacking. It may be observed, however, that the result obtained is different from what might have been expected. A hot and partly saturated air would not be selected on a priori grounds as a stimulating environment even for the rat. One can not, of course, without further proofs, carry these results over to other animals, but they should make us cautious in accepting generalizations in regard to the effect of the environment upon susceptibility to infection unless based upon experimental or good statistical evidence.

CONCLUSIONS

(1) Rats exposed for two weeks to a high temperature (83° F.) combined with a relative humidity between 44% and 72%, are more resistant to an intraperitoneal injection of pneumococcus than are rats kept at medium temperatures.

(2) With a high temperature humidity is a significant factor, the conditions for optimum resistance being

a relative humidity between 44% and 72%.

(3) Compared with this optimum condition, high and probably low humidity and medium temperature are unfavorable conditions.

(4) The relative humidity has no evident effect when the temperature is between 65° F. and 72° F., all conditions being equally unfavorable when compared with the optimum conditions of high temperature and medium humidity.

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BIOGRAPHY

Born December 10, 1895, in Baltimore, Maryland.

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Technical Assistant in the Division of Zoology of the Hygienic Laboratory, Washington, D.C., 1920-1921.

Student at the Johns Hopkins School of Hygiene and Public Health, 1921-1922.

Instructor in Physiology at the Johns Hopkins School of Hygiene and Public Health, 1922-1923.

TABLE 1, EXPERIMENT 20

HIGH TEMPERATURE AND MEDIUM HUMIDITY
COMPARED WITH A MEDIUM TEMPERATURE AND HIGH HUMIDITY

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Live
	D.B.	W.B.							
605♂	82.5°F.	75.5°F.	72	80	145	205			+
607♂	"	"	"	"	135	193			+
603♂	"	"	"	"	125	153			+
609♀	"	"	"	"	105	165	24 hrs.	+	
620♀	"	"	"	87	116	177			+
613♀	"	"	"	"	100	123			+
619♂	"	"	"	"	140	180			+
623♀	"	"	"	60	96	124			+
624♂	"	"	"	"	122	173	3 days	+	
627♀	"	"	"	?	121	141			+
611♂	67.0°F.	63.0°F.	80	80	147	204			+
606♀	"	"	"	"	127	162			+
610♀	"	"	"	"	98	127			+
615♂	"	"	"	87	105	150	24 hrs.	+	
616♀	"	"	"	"	113	142	3 days	+	
617♂	"	"	"	"	122	163			+
625♂	"	"	"	60	150	219	3 days	+	
622♀	"	"	"	"	97	121	2 days	+	
630♀	"	"	"	?	119	143	2 days	+	
628♀	"	"	"	?	125	175			+

TABLE 2, EXPERIMENT 21

HIGH TERPERATURE AND MEDIUM HUMIDITY
COMPARED WITH A MEDIUM TEMPERATURE AND HIGH HUMIDITY

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
703 ♀	83.0°F.	72.0°F.	58	72	103	115	4 days	+	
707 ♀	"	"	"	"	99	120	48 hrs.	+	
708 ♀	"	"	"	"	127	145			+
705 ♂	"	"	"	"	154	179	48 hrs.	+	
711 ♀	"	"	"	"	99	119	48 hrs.	+	
710 ♀	"	"	"	"	92	123	36 hrs.	+	
709 ♂	"	"	"	"	109	161			+
716 ♂	"	"	"	"	112	177			+
701 ♀	66.5°F.	61.6°F.	75	72	91	122	36 hrs.	+	
702 ♀	"	"	"	"	110	128	3 days	+	
706 ♀	"	"	"	"	114	139	24 hrs.	+	
704 ♂	"	"	"	"	181	206	24 hrs.	+	
713 ♀	"	"	"	"	83	108	36 hrs.	+	
715 ♀	"	"	"	"	104	112	48 hrs.	+	
714 ♀	"	"	"	"	91	112	36 hrs.	+	
712 ♂	"	"	"	"	99	138	48 hrs.	+	
717 ♂	"	"	"	"	119	173	48 hrs.	+	

TABLE 3, EXPERIMENT 25

HIGH TEMPERATURE AND MEDIUM HUMIDITY
COMPARED WITH MEDIUM TEMPERATURE AND MEDIUM HUMIDITY

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
1115 ♀	82.5°F.	75.5°F.	72	47	61	103	36 hrs.	+	
1116 ♀	"	"	"	"	72	114	60 hrs.	+	
1112 ♂	"	"	"	"	78	125			+
1101 ♂	"	"	"	68	123	143	24 hrs.	+	
1107 ♂	"	"	"	"	158	200	24 hrs.	+	
1102 ♂	"	"	"	"	148	181	48 hrs.	+	
1108 ♂	"	"	"	"	165	216	48 hrs.	+	
1111 ♂	"	"	"	48	111	161	3 days	+	
1109 ♂	"	"	"	"	87	137			+
1117 ♀	68.0°F.	56.0°F.	46	47	66	101	48 hrs.	+	
1114 ♂	"	"	"	"	81	121	48 hrs.	+	
1113 ♀	"	"	"	"	64	103	24 hrs.	+	
1106 ♂	"	"	"	68	168	193	48 hrs.	+	
1105 ♂	"	"	"	"	128	165	3 days	+	
1104 ♂	"	"	"	"	148	156	48 hrs.	+	
1103 ♂	"	"	"	"	134	187	48 hrs.	+	
1110 ♂	"	"	"	48	111	151	3 days	+	

TABLE 4, EXPERIMENT 26

HIGH TEMPERATURE AND MEDIUM HUMIDITY
COMPARED WITH A MEDIUM TEMPERATURE AND MEDIUM HUMIDITY

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
1208 ♀	83.5°F.	74.5°F.	66	45	68	121			+
1206 ♂	"	"	"	"	100	181	5 days	+	
1205 ♀	"	"	"	"	80	118			+
1204 ♀	"	"	"	"	86	124			+
1209 ♂	"	"	"	57	84	152			+
1212 ♀	"	"	"	"	60	115	2 days	+	
1218 ♂	"	"	"	"	68	141			+
1215 ♂	"	"	"	48	78	150	3 days	+	
1214 ♀	"	"	"	"	79	112			+
1207 ♀	67.5°F.	56.5°F.	49	45	81	130	4 days	+	
1203 ♀	"	"	"	"	88	141	5 days	+	
1202 ♂	"	"	"	"	94	176	4 days	+	
1201 ♀	"	"	"	"	102	147			+
1211 ♂	"	"	"	57	74	117			+
1210 ♂	"	"	"	"	70	123			+
1213 ♂	"	"	"	48	64	121			+
1216 ♀	"	"	"	"	55	91	4 days	+	
1217 ♂	"	"	"	"	77	154			+

TABLE 5

HIGH TEMPERATURE AND MEDIUM HUMIDITY
COMPARED WITH MEDIUM TEMPERATURE AND LOW HUMIDITY

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
EXPERIMENT 12									
48 ♀	83.5°F.	69.5°F.	49	55	76	111			+
37 ♀	"	"	"	"	81	109			+
27 ♂	"	"	"	53	85	125			+
28 ♂	"	"	"	53	70	103			+
26 ♂	"	"	"	"	74	115			+
23 ♂	"	"	"	"	66	94			+
34 ♀	73.5°F.	55.7°F.	29	55	76	110			+
35 ♀	"	"	"	"	82	107			+
45 ♂	"	"	"	"	77	111	7 days	+	
29 ♂	"	"	"	53	70	105	30 hrs.	+	
25 ♂	"	"	"	"	90	135			+
24 ♂	"	"	"	"	81	112			+
EXPERIMENT 11									
15 ♂	83.5°F.	69.5°F.	49	68	78	119	4 days	+	
7 ♀	"	"	"	"	79	123	36 hrs.	+	
14 ♂	"	"	"	"	109	170	48 hrs.	+	
16 ♂	"	"	49	"	127	180	48 hrs.	+	
19 ♀	"	"	"	57	83	124			+
24 ♂	"	"	"	"	108	161			+
13 ♂	73.5°F.	55.7°F.	29	68	118	188	48 hrs.	+	
8 ♂	"	"	"	"	62	111	48 hrs.	+	
25 ♂	"	"	"	57	74	132	48 hrs.	+	
23 ♀	"	"	"	"	81	121			+
17 ♂	"	"	"	"	89	158	48 hrs.	+	
1 ♀	"	"	"	84	118	137	4 days	+	

TABLE 6
HIGH TEMPERATURE AND HIGH HUMIDITY
COMPARED WITH MEDIUM TEMPERATURE AND HIGH HUMIDITY

EXPERIMENT 19

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
513 ♂	71.0°F.	68.0°F.	86	64	124	135	30 hrs.	+	
516 ♂	"	"	"	"	121	143			+
518 ♂	"	"	"	"	110	124			+
517 ♀	"	"	"	"	100	116			+
507 ♀	"	"	"	63	88	96	3 days	+	
504 ♀	"	"	"	"	88	104	3 days	+	
503 ♂	"	"	"	"	108	138			+
510 ♂	"	"	"	"	91	123			+
501 ♂	"	"	"	"	116	125			+
522 ♂	"	"	"	79	95	111	3 days	+	
521 ♂	"	"	"	"	104	130			+
511 ♀	83.5°F.	79.5°F.	84	64	114	140	24 hrs.	+	
515 ♂	"	"	"	"	111	133	24 hrs.	+	
512 ♂	"	"	"	"	135	164			+
514 ♀	"	"	"	"	96	116			+
506 ♀	"	"	"	63	91	107			+
508 ♂	"	"	"	"	89	101			+
502 ♀	"	"	"	"	101	112			+
505 ♂	"	"	"	"	102	130			+
509 ♂	"	"	"	"	116	144	5 days	+	
519 ♂	"	"	"	79	111	146			+
520 ♂					120	152	3 days	+	

HIGH TEMPERATURE AND HIGH HUMIDITY COMPARED WITH MEDIUM TEMPERATURE AND MEDIUM HUMIDITY

EXPERIMENT 16a

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
205 ♀	83.5°F.	79.5°F.	84	46	88	117	48 hrs.	+	
206 ♂	"	"	"	"	107	157	48 hrs.	+	
210 ♂	"	"	"	"	95	137			+
203 ♂	"	"	"	56	122	146	4 days	+	
201 ♀	"	"	"	"	110	125	4 days	+	
207 ♀	69.0°F.	59.0°F.	55	46	93	130	48 hrs.	+	
208 ♀	"	"	"	"	88	125	48 hrs.	+	
209 ♂	"	"	"	"	109	152	24 hrs.	+	
202 ♂	"	"	"	56	121	164	48 hrs.	+	
204 ♂	"	"	"	"	113	151			+

EXPERIMENT 14b

10 ♀	84.0°F.	80.0°F.	84	91	74	94	48 hrs.	+	
12 ♀	"	"	"	"	102	124	24 hrs.	+	
25 ♂	"	"	"	43	82	131	48 hrs.	+	
15 ♂	"	"	"	99	112	136			+
5 ♂	"	"	"	92	94	112	48 hrs.	+	
8 ♀	"	"	"	"	79	107	48 hrs.	+	
7 ♀	"	"	"	"	77	95			+
4 ♀	"	"	"	"	99	115	48 hrs.	+	
18 ♂	72.5°F.	63.5°F.	61	99	118	135	48 hrs.	+	
21 ♂	"	"	"	"	120	141	48 hrs.	+	
11 ♂	"	"	"	91	140	159			+
24 ♂	"	"	"	43	95	120	48 hrs.	+	
6 ♂	"	"	"	92	74	84	48 hrs.	+	

TABLE 8

HIGH TEMPERATURE AND HIGH HUMIDITY
COMPARED WITH HIGH TEMPERATURE AND MEDIUM HUMIDITY
EXPERIMENT 17

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
309 ♀	83.5°F.	79.5°F.	84	60	80	105	24 hrs.	+	
302 ♀	"	"	"	"	70	82	24 hrs.	+	
304 ♂	"	"	"	"	100	125	48 hrs.	+	
301 ♀	"	"	"	"	82	92	48 hrs.	+	
303 ♂	"	"	"	"	112	138			+
312 ♂	"	"	"	"	106	130			+
315 ♀	"	"	"	57	99	119	24 hrs.	+	
318 ♂	"	"	"	"	100	120	24 hrs.	+	
317 ♂	"	"	"	"	141	153			+
314 ♀	"	"	"	"	117	124			+
306 ♀	84.0°F.	68.5°F.	44	60	68	93	48 hrs.	+	
305 ♀	"	"	"	"	100	118	72 hrs.	+	
307 ♂	"	"	"	"	109	118			+
308 ♂	"	"	"	"	105	121			+
311 ♀	"	"	"	"	73	90			+
310 ♂	"	"	"	"	81	108			+
316 ♂	"	"	"	57	134	164	24 hrs.	+	
319 ♂	"	"	"	"	118	148			+
313 ♀	"	"	"	"	115	133			+
320 ♀	"	"	"	"	94	124			+

TABLE 9
HIGH TEMPERATURE AND MEDIUM HUMIDITY
COMPARED WITH HIGH TEMPERATURE AND LOW HUMIDITY

EXPERIMENT 22

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
808 ♂	83.0°F.	73.0°F.	62	64	120	175	24 hrs.	+	
811 ♀	"	"	"	"	108	130	48 hrs.	+	
812 ♂	"	"	"	"	127	185	48 hrs.	+	
802 ♂	"	"	"	"	157	187			+
809 ♂	"	"	"	"	122	175	24 hrs.	+	
801 ♀	"	"	"	"	100	128	7 days	+	
815 ♀	"	"	"	50	116	133	48 hrs.	+	
814 ♂	"	"	"	"	97	142			+
817 ♂	"	"	"	"	145	169			+
821 ♂	"	"	"	48	167	198	24 hrs.	+	
820 ♂	"	"	"	"	150	174	3 days	+	
807 ♂	85.0°F.	62.5°F.	25	64	126	149	24 hrs.	+	
810 ♂	"	"	"	"	137	177	24 hrs.	+	
806 ♀	"	"	"	"	95	112	24 hrs.	+	
805 ♂	"	"	"	"	123	166	60 hrs.	+	
803 ♂	"	"	"	"	128	170	48 hrs.	+	
804 ♂	"	"	"	"	125	157			+
813 ♂	"	"	"	50	85	135	48 hrs.	+	
816 ♂	"	"	"	"	129	172	48 hrs.	+	
818 ♂	"	"	"	48	173	190			+
819 ♂	"	"	"	"	144	173	48 hrs.	+	
822 ♂	"	"	"	"	130	155	24 hrs.	+	

TABLE 10
HIGH TEMPERATURE AND HIGH HUMIDITY
COMPARED WITH HIGH TEMPERATURE AND LOW HUMIDITY

EXPERIMENT 23

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
910 ♂	83.0°F.	79.0°F.	84	63	63	95	48 hrs.	+	
906 ♂	"	"	"	"	71	109			+
904 ♀	"	"	"	59	64	87			+
903 ♀	"	"	"	"	71	101	3 days	+	
901 ♂	"	"	"	"	108	150	7 days	+	
911 ♀	"	"	"	75	88	116			+
912 ♀	"	"	"	"	106	123			+
915 ♀	"	"	"	"	103	132	6 days	+	
907 ♂	85.0°F.	62.5°F.	25	63	77	121	48 hrs.	+	
908 ♂	"	"	"	"	68	112	48 hrs.	+	
909 ♀	"	"	"	"	78	103	4 days	+	
905 ♀	"	"	"	59	72	105	48 hrs.	+	
902 ♂	"	"	"	"	66	108			+
914 ♂	"	"	"	75	109	179			+
913 ♀	"	"	"	"	102	131			+
916 ♀	"	"	"	"	86	119			+

TABLE 11
HIGH TEMPERATURE AND HIGH HUMIDITY
COMPARED WITH HIGH TEMPERATURE AND LOW HUMIDITY

EXPERIMENT 24

Rat Number	Room Temperature		Relative Humidity (%)	Age of Rats (Days)	Weight when Experiment Began (Gms.)	Weight at Time of Injection (Gms.)	Time Before Death	Died	Lived
	D.B.	W.B.							
1009 ♀	83.0°F.	79.0°F.	84	63	108	152	48 hrs.	+	
1013 ♀	"	"	"	"	103	151	48 hrs.	+	
1010 ♀	"	"	"	"	96	132	48 hrs.	+	
1007 ♀	"	"	"	57	74	123			+
1002 ♀	"	"	"	"	81	139	48 hrs.	+	
1003 ♂	"	"	"	"	98	165	48 hrs.	+	
1018 ♂	"	"	"	62	87	130	24 hrs.	+	
1016 ♀	"	"	"	"	100	124	48 hrs.	+	
1019 ♂	"	"	"	55	113	170	48 hrs.	+	
1021 ♀	"	"	"	"	65	87	24 hrs.	+	
1011 ♀	85.0°F.	62.0°F.	25	63	106	135	36 hrs.	+	
1008 ♀	"	"	"	"	102	127	48 hrs.	+	
1012 ♂	"	"	"	"	100	140	48 hrs.	+	
1014 ♀	"	"	"	"	87	113			+
1001 ♂	"	"	"	57	88	157	24 hrs.	+	
1005 ♀	"	"	"	"	78	115	48 hrs.	+	
1006 ♀	"	"	"	"	90	127	48 hrs.	+	
1015 ♀	"	"	"	62	87	116	48 hrs.	+	
1017 ♂	"	"	"	62	110	152	60 hrs.	+	
1022 ♀	"	"	"	55	64	85	60 hrs.	+	
1020 ♂	"	"	"	"	88	130		∞	+

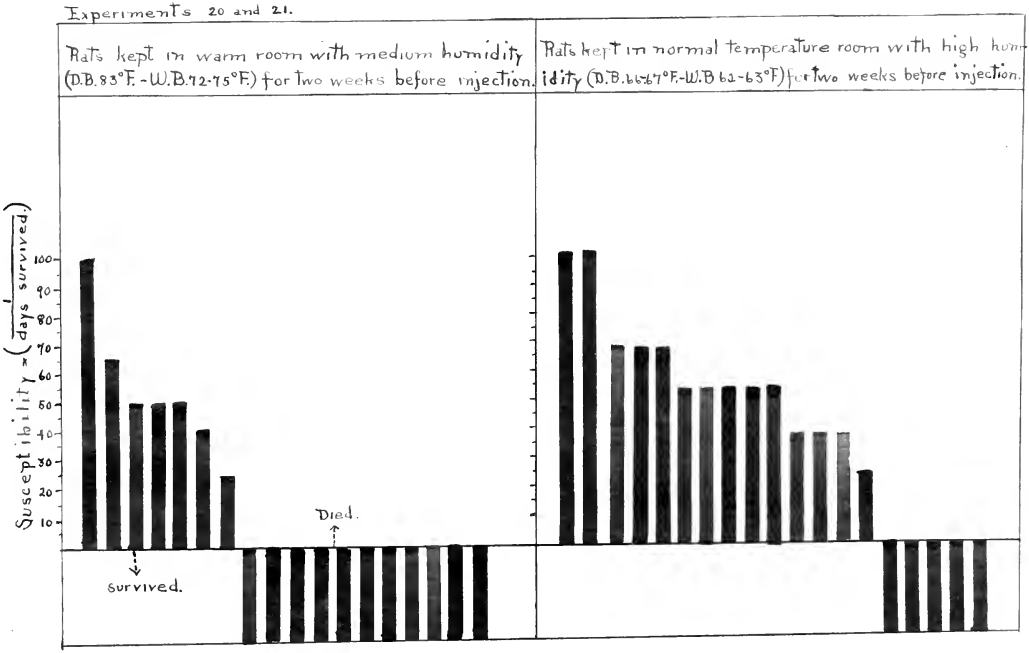
Experiments 20 and 21.
Rats kept in warm room with medium humidity (D.B. 83°F. - W.B. 72-75°F.) for two weeks before injection.
Rats kept in normal temperature room with high humidity (D.B. 66-67°F. - W.B. 62-63°F.) for two weeks before injection.
Susceptibility = (1/days survived)
100
90
80
70
60
50
40
30
20
10
Died.
survived.

Figure 2

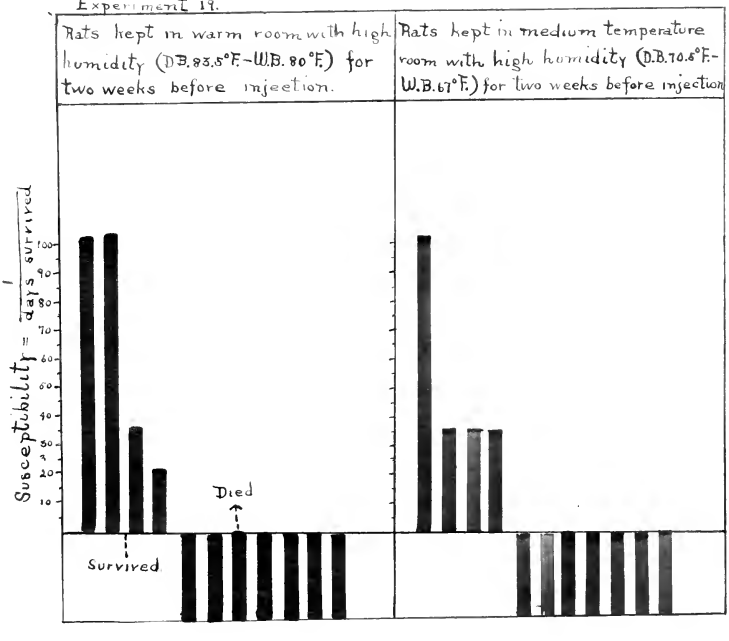
Experiment 19.
Rats kept in warm room with high humidity (D.B. 83.5°F.-W.B. 80°F.) for two weeks before injection.
Rats kept in medium temperature room with high humidity (D.B. 70.6°F.-W.B. 67°F.) for two weeks before injection
Susceptibility = 1/days survived
100
90
80
70
60
50
40
30
20
10
Died
Survived

Figure 3

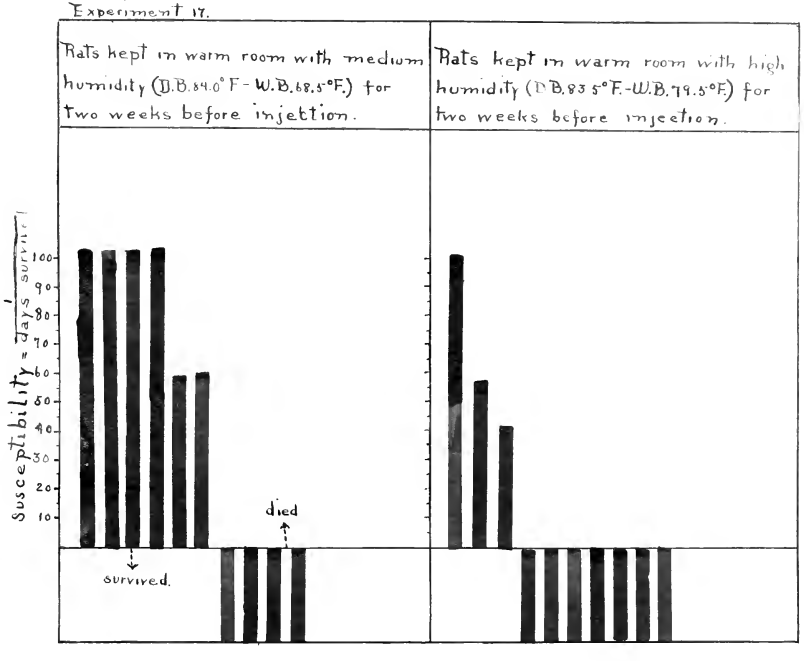
Experiment IV.
Rats kept in warm room with medium humidity (D.B. 84.0° F - W.B. 68.5° F.) for two weeks before injection.
Rats kept in warm room with high humidity (D.B. 83.5° F. - W.B. 79.5° F.) for two weeks before injection.
Susceptibility = 1/Days survived
100
90
80
70
60
50
40
30
20
10
died
survived.

Figure 4

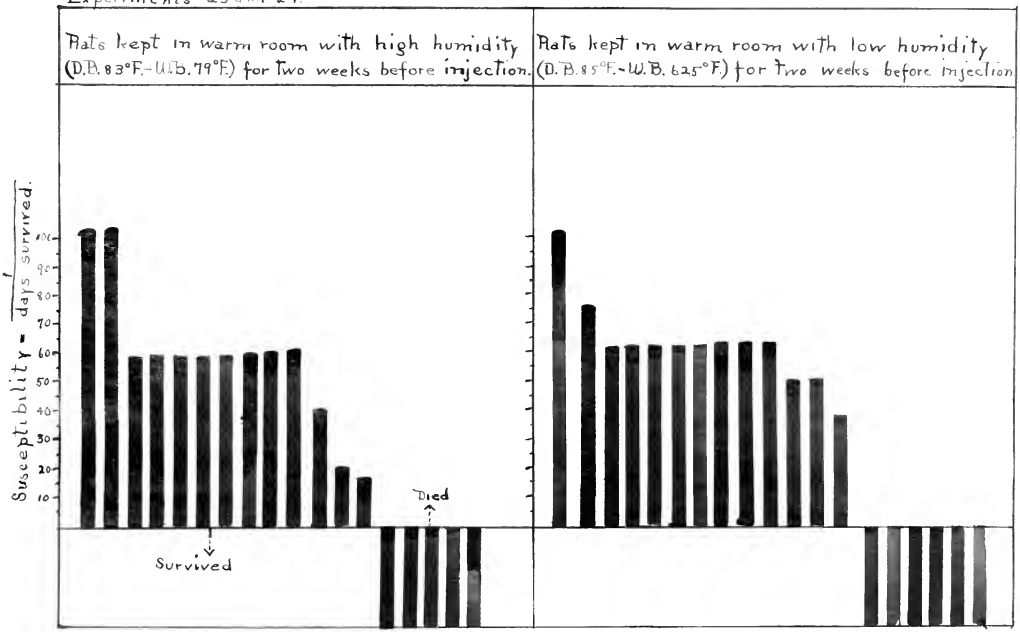
Experiments 23 and 24.
Rats kept in warm room with high humidity (D.B. 83°F.-W.B. 79°F.) for two weeks before injection.
Rats kept in warm room with low humidity (D.B. 85°F.-W.B. 625°F.) for two weeks before injection.
Susceptibility = 1/days survived.
100
90
80
70
60
50
40
30
20
10
Died
Survived

Figure 5

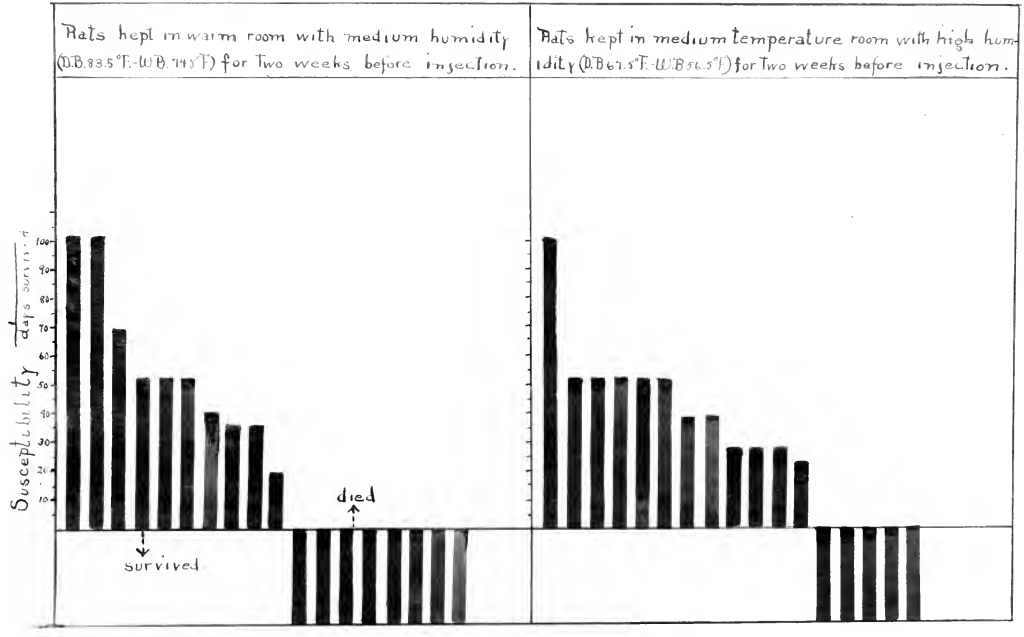
Experiments 25 and 26.
Rats kept in warm room with medium humidity (D.B. 83.5°F.-W.B. 74.5°F.) for Two weeks before injection.
Rats kept in medium temperature room with high humidity (D.B. 67.5°F.-W.B. 56.5°F.) for Two weeks before injection.
Susceptibility 1/days survived
100
90
80
70
60
50
40
30
20
10
died
survived

Figure b