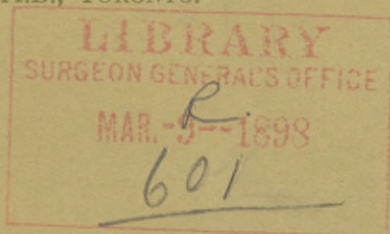


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DESCRIPTION OF RECORDING METHODS.

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Accepted as a Thesis for the Degree of Doctor of Philosophy in the Department  
of Biology at Clark University.

C. F. HODGE.

JUNE 19, 1897.





VARIATIONS IN DAILY ACTIVITY PRODUCED BY ALCOHOL AND BY CHANGES IN BAROMETRIC PRESSURE AND DIET, WITH A DESCRIPTION OF RECORDING METHODS.\*

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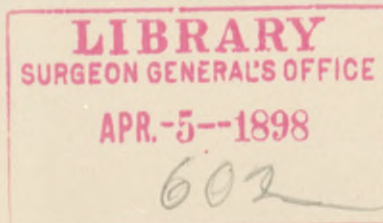
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IN a series of papers dealing with the laws of growth Minot<sup>1</sup> has pointed out the significance of experiments on organisms as individual wholes, as leading toward the proper object and final purpose of biological investigation, — the discovery of the laws of life. Growth, anabolic and accumulating, has its reverse in all forms of katabolism, of which by far the most important are the forms which supply from day to day and from hour to hour energy for those bodily functions which may be summed up under the broad name of "activity." If we grant that the activity of any individual organism may be an index of the sum total of its bodily conditions, then the study of the variations of that activity, and of the conditions which lead to such variations, becomes of the utmost importance.

With the commencement of such a study its difficulties begin. How is it possible to arrive at an adequate estimate of such activity? The present methods of Science can measure metabolism but exact chemical analyses would be impossible in a long series of experiments on normal animals. It becomes then clearly necessary to make many assumptions in devising a practicable method. In the research about to be described it has been assumed that the amount of muscular energy developed, in other words the amount of work

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COLIN C. STEWART.



done, by any animal day by day will be an approximate expression of its susceptibility to those variable conditions which may be chosen for experimentation. But here again new obstacles arise. No animal, even under conditions which may seem to be unvaried, will spontaneously show a uniform degree of activity for any series of days. Small causes, apparently inappreciable and unmeasurable, will produce changes tending to create or to destroy that feeling of bodily well-being which accompanies the proper functioning of all component parts. In studying the effect of drugs, for example, this difficulty becomes so overwhelming that it is plain that these small causes must be investigated for themselves. Weather changes, long recognized as potent, must be studied. The effects of atmospheric pressure, atmospheric moisture, temperature, light, winds and electrical variations must be obtained by long series of observations before we can hope to arrive at a solution of our single equation with its almost indefinite number of unknown quantities.

Of the meteorological factors just mentioned, only atmospheric pressure has been taken into consideration here. The methods of the research have nevertheless been applied for the purpose of studying the effects upon activity of variations in diet, and of the administration of alcohol, with the hope of obtaining results so broad and general as to be of value in showing at least the possibilities in this comparatively new field of operation.

So much for the purpose and aims of the undertaking. A word must be said as to the selection of suitable animals for the experiments. It seemed best to choose rats and mice, because they fill as many as possible of the requirements. They are small, cheap, easily fed and cared for; and, best of all, when placed in revolving cages they spend most of their time, when not eating or sleeping, in running.

With regard to the distribution of their working periods it may be noted that the records obtained from rats show that their activity is confined entirely to the hours of the night. Beginning at from six to eight o'clock in the evening—later in summer than in winter—they are uniformly, though not continuously, active during the next eight or ten hours. Contrasted with this is the activity of the squirrel, the records of which show greater intensity, but only for an hour or two night and morning. Still another type was that of two fox-squirrels, active throughout the whole of the day and sleeping only at night. Such differences indicate that an investigation of the



comparative distribution of activity and of the relation of its intensity to its duration promises interesting and valuable results. Commencing, as did Hodge and Aikins,<sup>2</sup> with the protozoa, it might be possible to develop much that would bear closely upon theories of animal rhythm, rest and sleep.

The following section will give a detailed account of the apparatus used, and of the general methods of procedure.

**Description of Apparatus and Methods.**—The apparatus consists primarily of two parts: the cages in which the animals to be experimented upon are placed, and the various mechanisms for recording their movements in these cages. Each of the cages (see Fig. 1) used throughout the experiments on rats is cylindrical, eighteen inches long by twenty in diameter, made of fine wire netting soldered to a

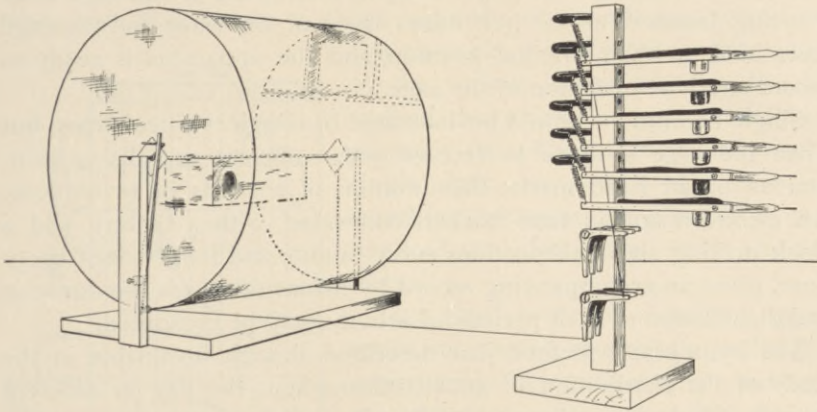


FIGURE 1.

frame of stout steel wire. The cage revolves freely on a steel rod supported by a fixed wooden frame. At one end is a wide-hinged door; from the axle is hung a light wooden nest-box, completely closed in but for a small round opening on one side; and to the end of the nest-box next the door is fixed a detachable tin feed-box of two compartments. At the opposite outer end of the cage is an eccentric which, with each revolution of the cage in either direction, pushes aside an upright lever attached to the wooden axle support, and in so doing pulls the wire connecting the cage lever with the recording apparatus.

Cages used for mice are similar in construction, except that their small size (eight inches long by five in diameter) renders them so

light that no wooden support is needed for the axle. The axle is held in position by a clamp upon an iron standard, while a second clamp holds a bearing for the lever which, with its wire, serves as a means of communicating the motions made by the cage.

To record the revolutions of the cages a simple six-inch continuous-roll kymograph, with uniform motive power, was first used. A standard carrying six light wooden levers, each five inches long, is placed before the kymograph. Each lever is tipped with thin whalebone, and to each is fixed a small glass ink-well and a pen of fine capillary glass tubing. Each is connected by a wire to the lever of the corresponding animal cage. As the cage revolves the eccentric pushes back the cage lever, the wire attached to it is pulled, the pen lever is drawn down, and the pen makes a vertical mark upon the slowly travelling scroll of paper. Upon the release of the cage lever a spring fastened to the pen draws the pen, the wires and the cage lever back to their original position, and the apparatus is ready to record another revolution of the cage.

Single revolutions would be indicated by single vertical lines, but when the cage is made to revolve with sufficient rapidity a continuous broad band marks the duration of a series of revolutions. An electro-magnetic time-marker, connected with a battery and a clock making short connections every minute and longer ones every hour, gives an accompanying record by means of which the duration and distribution of such periods of activity may be computed.

The kymograph method just described, though invaluable in the study of the distribution of activity throughout the day in different species of animals, and even in different animals of the same species, is nevertheless a rather unreliable one for close or accurate experimental measurement. After a rate of cage revolution has been reached which is sufficiently great to be recorded by a continuous broad band, no greater speed of revolution can be distinguished by any feature of the tracing. In other words, of two animals one might do twice as much work as the other in the same period of time without any indication of that fact being shown upon the record of their activity.

A much more exact recording method is the following, which has been used in almost all the experiments to be described. The hair spring and balance wheel of a common spring clock are removed, and to the escapement are attached, on one side a soft spring of fine brass wire, and upon the other a wire which, passing through a slit-



like opening in the clock case, is in turn attached, as was the wire in the preceding method, to the cage lever. Each revolution of the cage, as before, pulls the wire, the escapement is drawn down, and one cog of the ratchet wheel is let go. In the clocks used two of these cogs correspond to one second on the dial—seven thousand two hundred, therefore, to an hour. The clock is set at twelve, and the exact number of revolutions performed in any given time by the cage to which it is attached may, at the end of that time, be read off on the dial. This method fails to give any representation of the distribution of activity, but its relative accuracy in recording the total amount of work done makes it perhaps the most useful in experiments where daily variations due to food and drug effects are being sought for. By estimating the circumference of the cage used, and multiplying by the observed number of revolutions in any given time, one may obtain a rough estimate of the distance travelled.

For example, it was noted in the course of the various experiments to be described, that a common gray rat will run normally from five to fifteen miles in a single night, one particularly active rat travelling an aggregate distance of one hundred and forty-three miles in ten days.

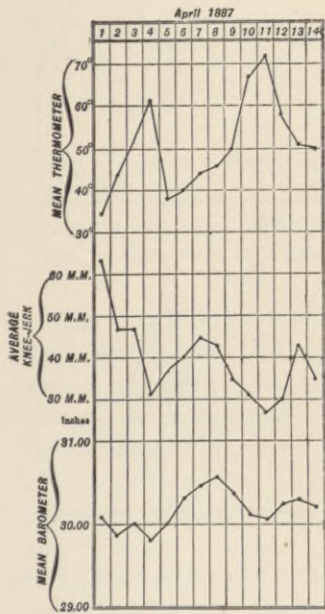


FIGURE 2. Knee-jerk, barometer and thermometer. (Lombard.)

the pen slowly rises as the string is wound up. By using a roll of paper carried on a kymograph at the rate of six or eight inches a day, and recording also thermometer, barometer, hygrometer and

time, a more or less complete picture of the data for the period studied may be obtained.

**The Effect upon Activity of Changes in Barometric Pressure.** — Lombard<sup>3</sup> has described a correspondence between the variations of average knee-jerk for a series of days, and the condition of the weather. His results (see Fig. 2) show a direct relation between knee-jerk and barometric pressure, and a more indefinite inverse relation to temperature. No effect of changes in humidity, or in electric tension, was shown. Lombard<sup>4</sup> has also shown, in experiments upon himself, that a decrease in atmospheric pressure lessens the ability to do voluntary muscular work, while an increase in pressure increases muscular power. High temperature, especially when associated with much humidity, decreases this ability.

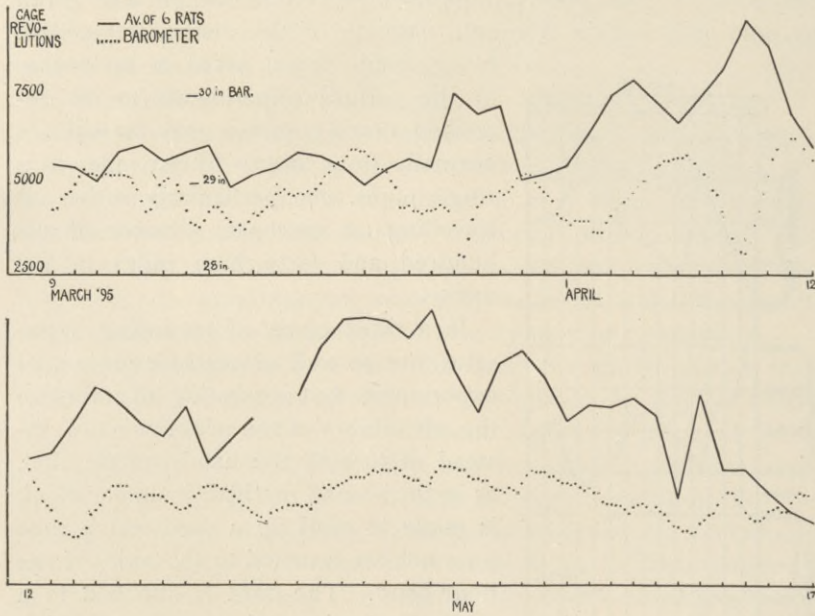


FIGURE 3. Curve of the average daily activity of six gray rats, during seventy days. The dotted line shows barometric pressure.

An undoubted influence of barometric variations upon the activity of the nerve muscle complex has, therefore, already been demonstrated, so that we might naturally expect to find variations in the amount of spontaneous daily work correlated with changes in atmospheric pressure. Turning to the experiments in which the methods



already outlined were used, we have in Figure 3 a curve, plotted in terms of cage revolutions, for seventy days, of the average daily activity of six common gray rats, full grown when caught, and therefore uninfluenced by domestication. The dotted line shows the variations in barometric pressure during the continuance of the experiment. Up to April twelfth, that is during the first half of the time, the rats were perfectly normal. During the latter half, however, four of them were getting alcohol in addition to their regular food. The consequent interference with normal activity is shown in the otherwise unaccountable rise during the latter part of April and the first few days of May. This will be referred to again more fully when the alcohol experiments are being described.

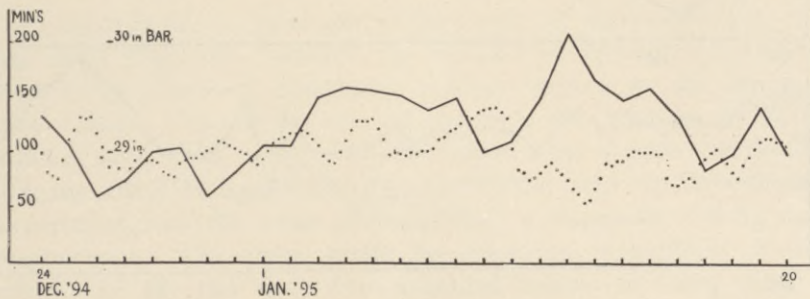


FIGURE 4. Curve of the daily activity in minutes of a single gray rat during twenty-six days. Barometer, as before, in dotted line.

Figure 4 is a curve of the variations in duration of activity shown by a single gray rat during twenty-six days. The curve of barometric pressure is superimposed in dotted line. In each of these curves there is shown an inverse relation between the amount of daily activity and the barometric pressure. Similar results were obtained from the records of a common red squirrel, though the squirrel's activity showed at times extreme variations from day to day with no apparent cause.

Figure 5 shows curves of the variations in daily activity of three groups of white rats for one hundred and twelve days. For the first twenty-six days the record is from five pairs of rats, one pair, male and female, to a cage; for the next twenty-six days six pairs are recorded, five of them being the five pairs of the preceding days; and for the rest of the time a new series of six pairs furnish the records. Where a point in the record has been enclosed in a

small circle, imperfect data have been used to fill out the space. The barometric pressure is recorded, as before, in dotted line.

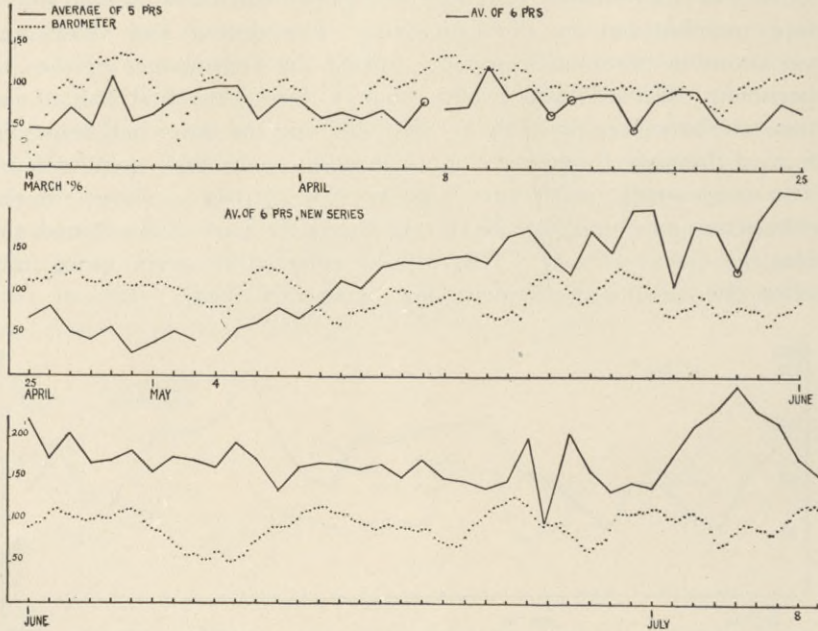


FIGURE 5. Curve of average daily activity of white rats: March 19th to April 7th, average of five pairs; April 8th to May 3d, of six pairs; May 4th to the end, of a new series of six pairs. Barometer in dotted line.

Whatever correspondence there is between the two curves would lead to the conclusion that the effect of changes in atmospheric pressure is a direct one, as against the inverse relation shown for gray rats. A point worthy of note, however, is that just as the pressure effect is shown more clearly in the curve of the first experiment where the animals are perfectly normal (see Fig. 3), so in this curve, from the beginning to the point marked April eighth, and from May fourth to June first, where the records are from normal rats, a correspondence is more clearly shown. During the rest of the time the same animals were being used for alcohol experiments, with a consequent interference as yet unexplained. Many of the daily variations in the curve are unaccounted for, but the great rise in average activity shown during the early part of July is without doubt due to the disturbing noises incident to the celebration of Independence Day.



Figure 6 gives another curve of the average activity of six white rats, with barometer plotted in dotted line as before. Here again the correspondence between the curves is only of doubtful value.

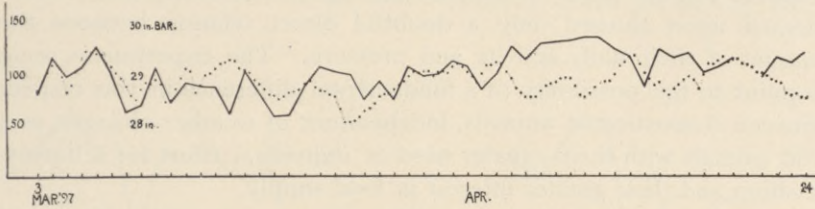


FIGURE 6. Average activity of six white rats for fifty-three days. Barometer in dotted line.

Figure 7 shows, in solid and broken line, the curves of activity of two dogs, from data obtained by Hodge<sup>5</sup> by means of a pair of ingeniously contrived pedometer watches carried by the dogs in their collars. The curves are plotted from the readings of these watches taken once a day. To the chart I have added in dotted line the curve of barometric pressure for the forty-six days of the experiment, with the result of establishing a somewhat striking correspondence. The curve would be improved in legibility if the records for the two dogs were averaged instead of being plotted

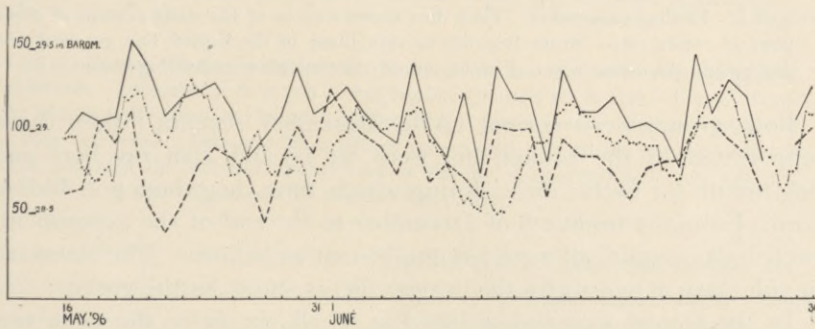


FIGURE 7. Curves of the activity of two dogs, plotted in solid and broken line. Barometric variations shown in dotted line for the forty-six days of the experiment.

separately, as they are in the figure; but it would not show, as it does now, the remarkable similarity between the two. Other measurable factors are undoubtedly at work in producing variations, — factors which can be determined only by manifold repetition of such experiments.

The foregoing charted results show an inverse relation between the amount of voluntary daily activity of gray rats and atmospheric pressure, and a direct relation between variations in barometric pressure and the activity of the two dogs. The white rats experimented upon showed only a doubtful direct relation between the amount of their daily activity and pressure. The experiments seem to point to the possibility of a fundamental difference in this respect between domesticated animals, independent of weather changes, and wild animals with their greater need of individual effort for self-preservation and their greater interest in food supply.

**The Effect of Changes in Diet.** — The experiments under this head were all upon white rats normally fed on a uniform diet of dog-biscuit and water. In the first experiment (see Fig. 8) six pairs of white rats, one pair to a cage, were used. The solid line shows the average daily activity of three pairs, the broken line that of the other three.

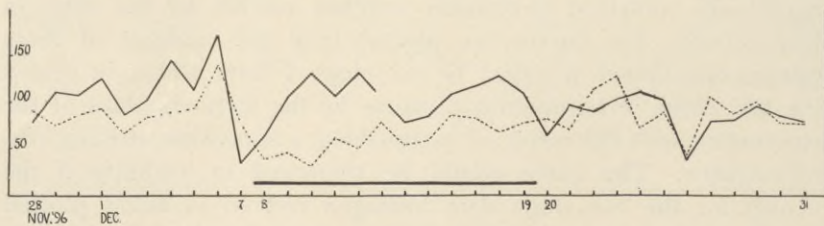


FIGURE 8. Feeding experiment. Each line shows a curve of the daily average of three pairs of white rats. From Dec. 8th to 19th those of the dotted line get beef and dog-biscuit, the others corn. For the rest of the time all were fed dog-biscuit.

Both groups were normal up to December seventh; then those represented by the broken line were fed fat and lean raw beef and dog-biscuit for twelve days, during which time the others got Indian corn. From the twentieth of December to the end of the experiment, twelve days again, all were fed dog-biscuit as before. The decrease in voluntary activity with the heavier diet is shown in the curve.

In the second experiment (see Fig. 9) all six pairs, the same rats as were used in the preceding experiment, were fed alike. For the first twelve days they were fed on dog-biscuit, with good average records as the result. During the next fifteen days (January first to fifteenth) white bread was given, with an accompanying increase in the amount of daily work. For the next ten days (January sixteenth to twenty-fifth) bread and fat and lean beef were given, causing a manifest decrease. Then for six days (January twenty-sixth to



thirty-first) bread alone, as before, was fed, with again a rise. This was followed by bread and beef for seven days (February first to seventh) with a fall in activity. From the eighth of February to the end of the experiment on the first of March bread alone was fed,

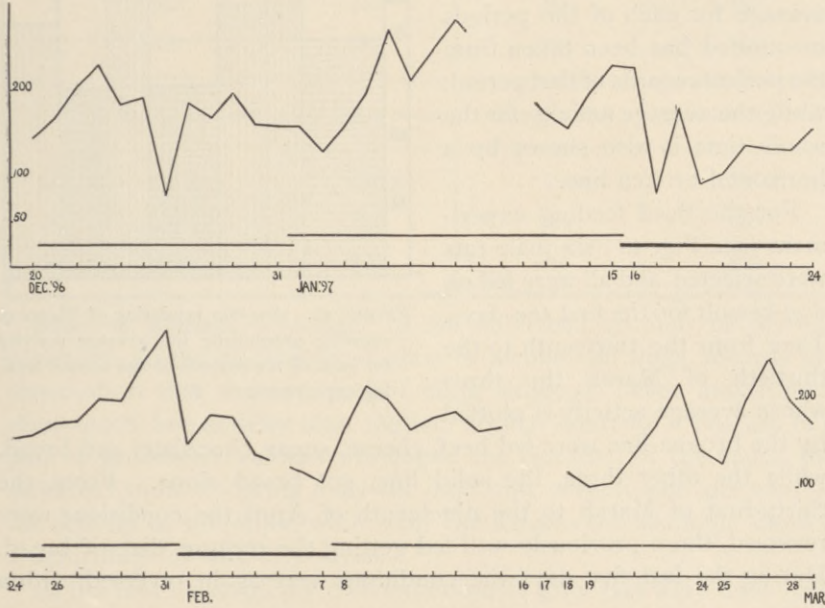


FIGURE 9. Second feeding experiment. Curve shows average activity of six pairs of white rats. December 20th to 31st — dog-biscuit. January 1st to 15th — bread. January 16th to 25th — beef and bread. January 26th to 31st — bread. February 1st to 7th — beef and bread. February 8th to March 1st — bread. At points marked February 18th and 19th the effect of lack of food is shown; at February 24th and 25th, the effect of an escape of gas, and the same at March 1st.

with a resulting rise in activity. The record for this last period remains uncomplicated, however, during only the first eight days. On the seventeenth of February the record for the preceding night was not noted, nor were the rats fed. The records for the sixteenth and seventeenth were therefore lost, while the records for the eighteenth and nineteenth show the effect of insufficient food. Recovery was complete by the twenty-third, when unfortunately gas escaped in the room in which the experiments were carried on, and several of the rats were noticeably poisoned by it — the effect upon their activity being shown by the records of the twenty-fourth and twenty-fifth. Re-

covery again followed, when, on the twenty-eighth, gas escaped once more, with a similar result.

The next figure shows in another way the result of this experiment (see Fig. 10). The average for each of the periods mentioned has been taken from the perfect records of that period, while the average activity for the whole time is also shown by a horizontal broken line.

For the third feeding experiment (see Fig. 11) six male rats were selected, and all were fed on dog-biscuit for the first ten days. Then from the thirteenth to the thirtieth of March the three whose average activity is plotted

by the broken line were fed beef, cheese, sugar, chocolate, and bread, while the other three, the solid line, got bread alone. From the thirty-first of March to the nineteenth of April the conditions were reversed, those previously well fed getting the meagre diet of bread. During the last five days the conditions were again reversed, with a

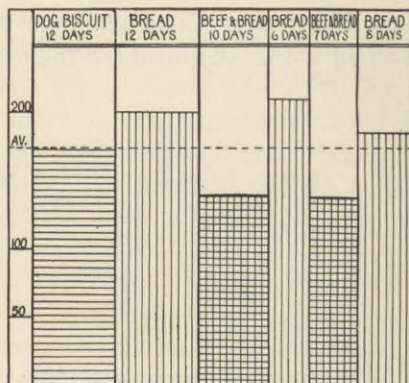


FIGURE 10. Another rendering of Figure 9, showing graphically the average activity for each of the periods of the second feeding experiment.

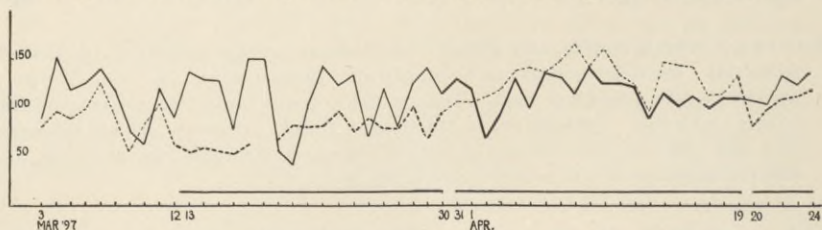


FIGURE 11. Third feeding experiment. Each line the average of the records of three male rats. All normal to March 12th. March 13th to 30th, full diet for those of the broken line and bread for the others. March 31st to April 19th, full diet for those of the solid line, and bread for the others. April 20 to 24th, the conditions again reversed.

second crossing of the lines of activity as the result. The simpler diet in all cases gives a relatively greater degree of activity. The weights of the rats were taken at the commencement of the experiment, at each change, and at the end. The following table shows the increase in weight that accompanied the decrease in activity.



Rat No.	March 3d. Commencement.	March 31st. After rich diet.	April 20th. After diet of bread.	April 25th. After rich diet.
1	305 g.	329 g.	310 g.	325 g.
2	312	335	322	325
3	235	249	238	240
	Commencement.	After diet of bread.	After rich diet.	After diet of bread.
4	315 g.	307 g.	332 g.	326 g.
5	300	281	286	280
6	260	231	256	255

**Effect of Alcohol.**—Hodge,<sup>5</sup> in the published account of his experiments on the physiological effect of alcohol on dogs, records the observation that the two alcohol dogs, although never intoxicated, show much less activity than the two normal controls. The use of a pair of pedometer watches developed the fact that, of the males, the alcoholic showed during forty-six days only seventy-one per cent of the activity of the other, while with the females the alcoholic showed a percentage of only fifty-seven.

In the first series of my own experiments gray rats were used. Six rats of as nearly equal weights as could be found were placed in six similar cages and kept on a normal and entirely uniform diet for longer or shorter periods before the actual commencement of the experiment. Averages of their activity for such periods were taken on April twelfth, 1895, and the rats were arranged in pairs in such a way that the total average activity of any one pair was as nearly equal to that of either of the other two pairs as possible. It was decided to give weak alcohol to two, strong alcohol to two, and to keep the other two as normal controls. Alcohol was administered with their food in increasing strength, according to the following schedule:

	April 12th.	15th.	22d.	27th.	May 2d.	6th.	10th.	14th.
Normals . .	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Weak . . .	5	10	15	20	—	—	—	—
Strong. . .	5	10	15	20	30	40	50	60

So that one pair from April twenty-seventh to the end of the experiment in October of the same year drank nothing but twenty per cent alcohol, while another pair had a sixty per cent solution after May fourteenth.

Figure 12 shows the voluntary activity of these six rats during the experiment. The solid line is the curve of the average of the two normal rats, the dotted line that of the weak alcohol rats, and the

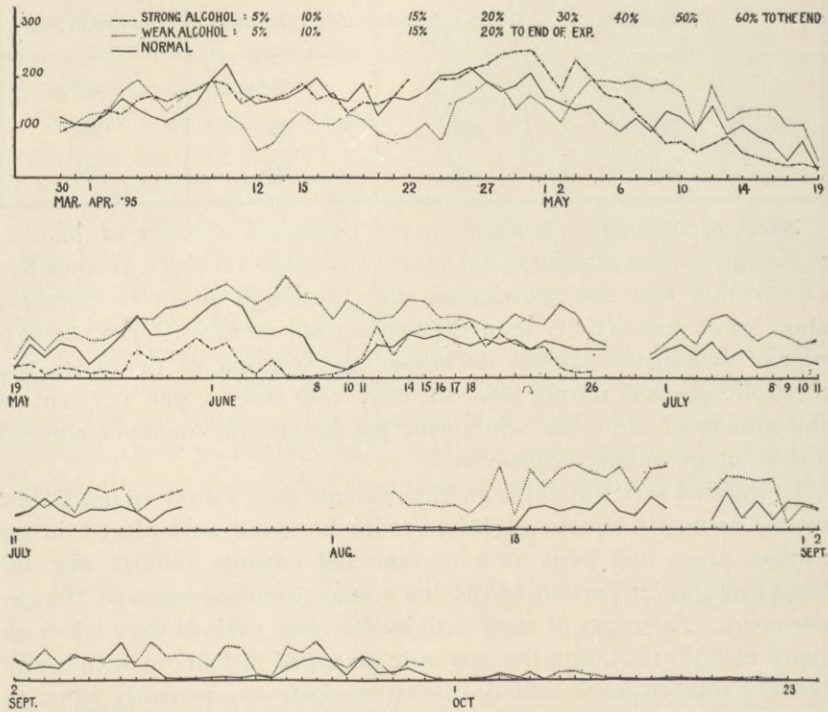


FIGURE 12. Alcohol experiment upon gray rats. Solid line plots the average of two normal rats; dotted line, of two getting weak alcohol; and broken line, of two getting strong alcohol. Water given June 8, 10, 11, 14, 15, 16, 17 and 18, and July 8, 9 and 10.

broken line, that of the strong. One of the rats getting the strong solution died on the seventeenth of May, the second on the twenty-sixth of June. On the eighth, tenth, eleventh, fourteenth, fifteenth, sixteenth, seventeenth and eighteenth of June, and on the eighth, ninth and tenth of July, water was substituted for alcohol. The result was a decided rise in the activity of the strong alcohol rats and no definite effect upon the weak alcohol animals. The



general falling off in activity toward the end of the experiment is no doubt partly due to the lack of variety and general insufficiency in diet.

Figure 13 gives another rendering of the same curve, with the normals plotted as a level line and the others shown as varying above and below that normal. The broken line is the curve of the strong

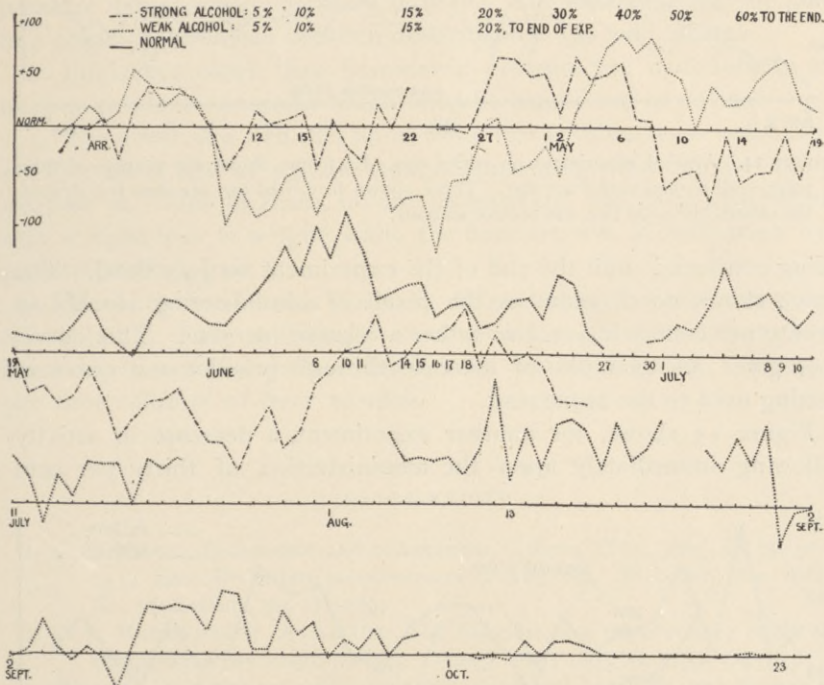


FIGURE 13. Another chart of the same experiment. Activity of normal rats taken as base line; strong alcohol rats in broken line, and weak alcohol rats in dotted line. Water given June 8, 10, 11, 14, 15, 16, 17 and 18, and July 8, 9 and 10.

alcohol rats, and the dotted line that of the weak. It shows perhaps better than Figure 12 the primary rise in the activity of the rats getting strong alcohol, with a subsequent fall as soon as forty per cent is given, and the rise again during the month of June when water was substituted. For the animals getting weak alcohol it shows a slower rise but no subsequent fall to the level of the normals for any length of time.

Figure 14 is a chart showing the result of an experiment upon six pairs of white rats, one pair, male and female, to a cage. Three

pairs are normal throughout, their average daily activity being plotted in solid line. The other three are normal for twenty-nine days, until June second, when five, ten, fifteen and twenty per cent alcohol are given on four successive days, the twenty per cent alcohol

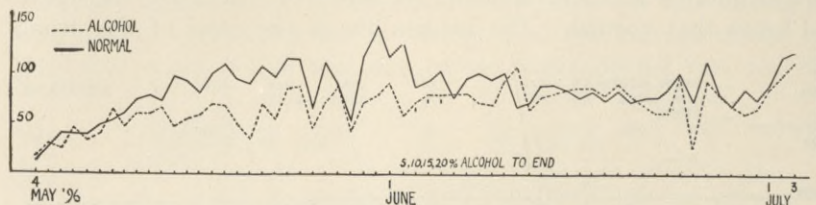


FIGURE 14. Alcohol experiment on white rats. Each line shows the average of three pairs—all normal until June first. Those shown in dotted line are then fed alcohol; the others, the solid line, are control animals.

being continued until the end of the experiment on July third. The curve shows no decrease as the result of administering alcohol in twenty per cent solution, but rather a relative increase. This curve, too, gives an example of increase through practice—a curve of getting used to the apparatus.

Figure 15 shows, for another experiment, a decrease in activity following immediately upon the administration of thirty per cent

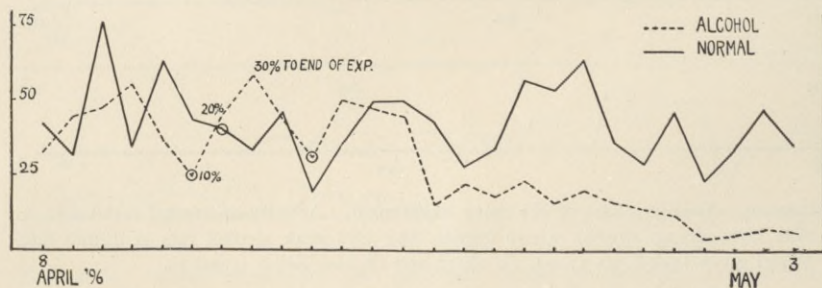


FIGURE 15. Alcohol experiment on white rats. Each curve shows the average of three pairs. The solid line shows the activity of the normal animals, the broken line that of the alcoholic animals. Alcohol given as indicated. Points enclosed in small circles are filled in from imperfect data.

alcohol. As in the preceding experiment, six pairs of white rats, three for alcohol and three for controls, were used. Points enclosed in circles are filled in from imperfect data.



## CONCLUSIONS.

1. While the experiments show, for gray rats and for a red squirrel, an influence of barometric pressure on voluntary, spontaneous activity that indicates an inverse relation between the two, the curves for dogs, and possibly also for white rats, show a direct effect of atmospheric pressure in increasing voluntary activity. The difference may be due to a constant difference between domesticated and wild animals.

2. Influences other than barometric pressure are undoubtedly at work to produce variations which must be considered as normal.

3. The effect of a rich diet upon white rats is to decrease voluntary activity, while that of a plain though apparently sufficient diet is to increase it. This increase, in one experiment, has been correlated with a slight loss in weight, while the decrease was accompanied by a corresponding gain.

4. The activity of rats is markedly decreased by the administration of alcohol in thirty to sixty per cent solutions, but no decrease has been experimentally demonstrated as a result of giving a twenty per cent solution of pure alcohol.

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