THE RESPONSE OF POPILLIA JAPONICA TO LIGHT AND THE WEBER-FECHNER LAW.

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(Received for publication, October 26, 1920.)

The Japanese beetle, *Popillia japonica*, is a recent importation from Japan and is found in a limited area in central New Jersey.

During July and the first half of August the beetles may be seen collected in great numbers at the tops of trees, bushes, and weeds. It seems to be immaterial whether the plant is a linden tree 50 feet high or a smartweed plant a foot high—the beetles always occupy the uppermost foliage. This is due to the fact that the direction of movement in these beetles is the additive resultant of two tropistic responses; namely, positive phototropism and negative geotropism. These tropisms determine the head-tail orientation of the body.

Both in the field and in the laboratory a certain degree of heat and of light is necessary for the active movements of *Popillia*. Thus, below 23°C. the beetles are generally inactive; 38–39°C. is optimum for their activity, while above 40°C. injurious effects are apparent. At 45°C. activity ceases quickly and permanently. Under the ruby light and in the dark most of the beetles become quiet and show no response to gravity. Occasional individuals which do move show a retarded response. All are roused to activity by illumination from any direction, while a great increase in the strength of the light causes marked acceleration of movement and flying.

In addition to this kinetic action of light there is also a directive effect, which may be demonstrated by illuminating the beetles first from above and then from below and timing their response in each case. Without exception they ascend the wire gauze of their cage more rapidly in the first instance, although in the latter case the

* The apparatus for this work was furnished by Rutgers College, New Brunswick, N. J.

animals eventually reach the top, thus proving the geotropic response to be the major factor in orientation. Table I shows the retarding effect of illumination from below. Incidentally these figures well illustrate the constancy with which any given lot of animals responds. It is apparent from this result that while light exercises a directive action, the directive effect of gravity is greater than that of light of the strongest intensity used.

Since the geotropic response is shown by the beetles only when illuminated, it therefore follows that their movement in a lighted field is the result of three factors; *viz.*, negative geotropism, photo-

TABLE I.

*Light Intensity 3,276 Candle Meters.**

Light above.	Light below.
Reaction time.	Reaction time.
sec.	*sec.*
10	15
11	16
9	17
11	17
11	15
Mean..........10.4	16

* With the light above, gravity and light act together to produce a response in 10.4 seconds. When the light is below, the directive action of the light acts against the effect of gravity and thus delays the response to 16 seconds.

kinesis, and positive phototropism. The first is constant, the other two factors are functions of the intensity of the illumination. In the case in which the light is from above, it follows that changes in the rate of movement of the beetles depend on variations in the degree of photokinesis and of phototropism. These factors in turn depend upon the intensity of the illumination. Hence we may express the relation of the rate of response to the intensity of the illumination by saying that the rate of response is a function of the light intensity.

In the present study, the determinations of reaction time were made as follows. A cage of wire gauze 12.5 cm. high was constructed, having a movable top of the same material. During a series of experiments this cage containing twelve female beetles was kept in a thermostat made of glass at a temperature of approximately 38.5°C. with extreme variations for short intervals on two or three occasions during the season to 37.5 and 39.5°C. Five intensities of illumination were secured by the use of Mazda glowers of different powers. During the experiment the glower was held by a clamp 25 cm. from the top of the cage. The latter was protected from the heat of the lamp by a water screen. In making the observations one observer manipulated the cage by inverting it for each start and then noted the instant that six beetles (50 per cent of all) reached the top of the cage. The start and stop were signalled to the second observer who kept time with the stop-watch and recorded the time intervals to the nearest

TABLE II.*

I	$\log_e I$	Reaction time.	$R = \frac{100}{\text{Reaction time}}$	$R = \frac{\log_e I + K}{k}$
			Observed.	Calculated.
		sec.		
85	4.44	15.50	6.45	6.56
234	5.45	13.14	7.61	7.49
608	6.40	11.60	8.62	8.36
1,600	7.37	10.86	9.21	9.25
3,276	8.08	10.22	9.78	9.90

* I = the intensity of the light in candle meters, R = rate at which the organ isms respond, k = 1.09, and K = 2.71.

second. Five observations were made at each intensity with each lot of twelve animals. Seven such series were run. Each point is therefore the result of thirty-five observations. The mean of the values obtained for each intensity is given under the heading "Reaction time" in Table II. The rate is equal to $\frac{100}{\text{Reaction time in seconds}}$.

We have assumed that the rate of movement is an objective measure of the effect of light on the organism, *i.e.* sensation, and now proceed to consider our experimental results in the light of the Weber-Fechner concept. According to Weber's law, the least noticeable difference of a stimulus is proportional to the magnitude of the pre-existing stimulus. Fechner[1] has expressed this relation in the form

[1] Fechner, G. T., Elemente der Psychophysik, Leipsic, 1860, i, 211.

of a differential equation according to which $dS = c.\frac{dI}{I}$, in which S = the magnitude of sensation, I is the intensity of the exciting cause, and c is the constant of the series. Integrating, this equation becomes $S = c.\log_e I + K$. This means that the sensation is proportional

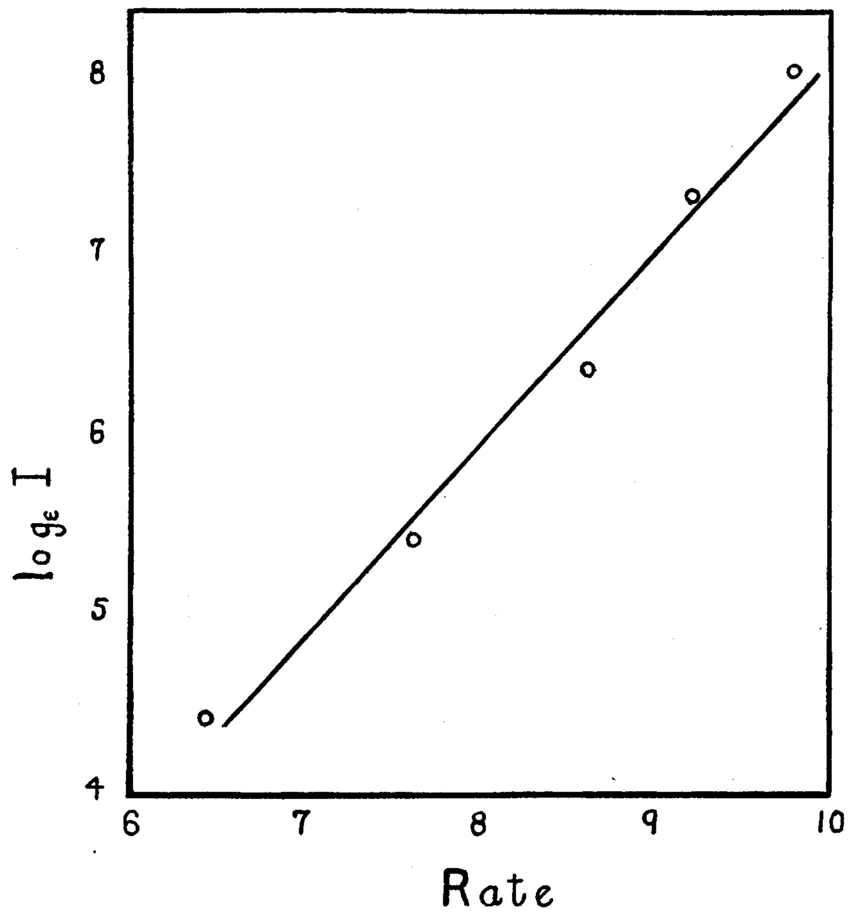

FIG. 1. The small circles show the experimental points in which Rate = $\frac{100}{\text{Reaction time in seconds}}$; the line is drawn through the points calculated for the rate by means of the equation, Rate = $\frac{\log_e I + K}{k}$.

to the logarithm of the intensity of the stimulus. Putting R, the rate of response, for S, transposing and putting k for $\frac{1}{c}$, the integrated equation of Fechner becomes $\log_e I = kR - K$.

Substituting the experimental values of $\log_e I$ and of R in this equation and solving by the method of least squares for k and K we obtain $k = 1.09$ and $K = 2.71$. These quantities when put into the equation for each value of $\log_e I$ in turn yield a series of calculated values for R, as shown in the last column of Table II.

When the rates are plotted as abscissæ against the values of $\log_e I$ as ordinates the result is a straight line (Fig. 1), showing at a glance that the rate of response of the organism to light is proportional to the logarithm of the intensity of the illumination. This demonstrates that the Japanese beetle responds to light in accordance with the Weber-Fechner law.

SUMMARY.

Light and a temperature above 23°C. are necessary for the activity of *Popillia.*

The effect of light as indicated by the rate of locomotor response is related to light intensity according to Fechner's expression of Weber's law.