THE INFLUENCE OF THE INTENSITY OF LIGHT ON THE RATE OF GROWTH AND DURATION OF LIFE OF DROSOPHILA.

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Although light is one of the most striking attributes of the environment of living organisms, the results of practically all of the experiments designed to show the effect of light on the normal growth processes of animals have been negative. This is the more surprising in view of the marked effects which have been reported in connection with abnormal or pathological conditions. Aseptic cultures of Drosophila have been propagated in this laboratory for over 200 generations and during that time have been kept in the dark except for occasional exposure to diffuse daylight, and they would seem to be favorable material for a study of the influence of light on normal growth. The present experiments were undertaken to determine whether or not the rate of growth and total duration of life of these insects would be affected by variations in the intensity of light.

EXPERIMENTAL PROCEDURE.

Source of Light.—The light source was a concentrated filament Mazda bulb of 150, 500, or 1,000 watts. The bulb was immersed in a vessel of running water and surrounded by a layer of about 1 cm. water. The intensity was measured approximately by a Lummer-Brodhun contrast photometer against a standard Hefner amyl acetate lamp. The bulbs were frequently changed.

Culture Medium.—The flies were grown and transferred in 500 cc. Pyrex flasks having a side arm as previously described.1 For the rate of growth of the larve 10 cc. of a suspension of 40 gm. of yeast in 100 cc. of 2 per cent glucose agar were placed in a 500 cc. flask and sterilized. A number of freshly hatched flies from the stock culture were then put in the flask and the flask placed in the dark. After 24 hours the flies were removed and the flask placed in the

proper position. The imagos were raised on yeast in the dark, and were then transferred to glucose agar alone, which is sufficient for their maintenance but insufficient for growth of the larvae so that it was unnecessary to transfer the adult flies. About 100 larvae or imagos were used in each experiment, and the probable error of the mean was in all cases between 2 and 3 per cent.

The experiments were made in a constant temperature room in which the air was circulated with a powerful fan. Temperature readings with a mercury thermometer at different distances from the light showed at times an increase of about 1°C. at a distance of a foot from the light and it is possible that this is in part the cause of the increased growth rate at this distance.

![Diagram showing influence of light intensity on growth and duration of Drosophila](image)

**Fig. 1.** Influence of the intensity of light on the rate of growth and duration of life of *Drosophila*.

The results of the experiments are shown in Fig. 1, in which the duration of the various stages in days has been plotted against the logarithms of the intensity of illumination expressed in meter candles. This intensity was varied by varying either the distance from the light, assuming the inverse square law, or the intensity of the light itself. The results show that up to light intensities of about 600 meter candles there is no change either in the rate of growth or in the duration of
life of the imago. Above this intensity the duration of life of the imago rapidly decreases while the duration of the larval period decreases slightly and then increases. There is no effect on the pupae except that above 5,000 meter candles the pupae are killed. As is the case with temperature the pupal stage is the most sensitive. It is possible, as stated above, that the decrease in the larval period (increase in the rate of growth) is due in part to a temperature difference. The result is in any case similar to that obtained with temperature in which it was found that there was an optimum temperature for the larval growth but not for the duration of the imago stage. Apparently injury from either temperature or light results at first in an increase in length of the larval or growth period but a decrease in the imago or adult period, whereas in the normal range both periods are influenced in the same direction. It is interesting to note in this connection that anything which increases the rate of growth, i.e. shortens the growth period, is usually considered a beneficial effect, whereas anything which increases the rate of life, i.e. shortens the adult period, is considered harmful. To be consistent it would seem that a decrease in the rate of growth (which is equivalent to prolonging the length of the growth period) is just as beneficial to the organism as increasing the duration of the adult period, and the writer has shown in fact that decreasing the rate of growth results in adding an equivalent number of days to the total duration of life.\footnote{Loeb, J., and Northrop, J. H., \textit{J. Biol. Chem.}, 1917, xxxii, 103.}\footnote{Northrop, J. H., \textit{J. Biol. Chem.}, 1917, xxxii, 123.}

\textbf{The Relation between the Duration of Life and the Intensity of Illumination.}

The experiments show that the duration of the imago stage is not affected within the experimental error up to 640 meter candles and that above this point the duration of life decreases rapidly and approximately in proportion to the logarithm of the intensity.

There is probably no doubt that the observed effect is the sum of two reactions, first, the normal "aging," and second, the effect of the light. The total rate of reaction, $K_\omega$, would therefore be the sum of two reaction velocities, one the normal velocity, $K_\alpha$, and the other the velocity $K_I$ due to the light; i.e., $K_\omega = K_\alpha + K_I$.\footnote{Loeb, J., and Northrop, J. H., \textit{J. Biol. Chem.}, 1917, xxxii, 103.}\footnote{Northrop, J. H., \textit{J. Biol. Chem.}, 1917, xxxii, 123.}
When the illumination is 0, \( K_o = K_a \) so that the value of this velocity can be determined from the duration of life in the dark. It is necessary to know also in what way the rate of reaction due to the light varies with the intensity of illumination. It might be expected that the rate of reaction would increase with the logarithm of the intensity as predicted by the Weber-Fechner law. This assumption would predict, however, that the observed rate (reciprocal of the time) would give a straight line if plotted against the logarithm of the illumination. This is evidently not the case, however, unless the entire first part of the curve up to 640 meter candles be neglected. It is true that from that point an approximately straight line is obtained. It is known, however, that in most photochemical reactions the velocity of the reaction is directly proportional to the intensity of illumination. Using this assumption, the velocity of the reaction due to the light would be proportional to the light intensity; i.e., \( K_e = CI \).

The equation for the whole process, assuming the velocity equal to the reciprocal of the time, therefore would become

\[
K_e = \frac{1}{T_o} = K_a + CI
\]

(1)

As stated above, when \( I \) is zero, \( K_o = \frac{1}{T_o} = 5.7 \). If this value is substituted at the point where \( I = 2,500 \), \( C \) is found equal to \( 27 \times 10^{-8} \). If the assumptions used are justified, it should be possible to calculate the experimental results from these values of \( K \) and \( C \). That this is true is shown in Table I. The observed values for the duration of life at varying intensities agree closely with those calculated by means of equation (1).

According to the above mechanism the light does not simply speed up the normal "rate of aging" but produces a separate reaction or reactions. This can be tested by noting the effect of short exposures. Table II contains the results of an experiment in which the flies were exposed for 3 days to 10,000 meter candles. This experiment was carried out with a different culture of flies and was at 25°C, so that the results are not directly comparable with the preceding ones. The flies which were not exposed to the light lived on the average 13.5 days, those that were continuously exposed lived 3.9 days, and those
that were exposed for 3 days and then placed in the dark lived 7.9 days. Very few of them had died before removal from the light. If the light merely accelerates the velocity of the normal reaction, the flies after 3 days exposure should be the same as those that had lived the same percentage of their life in the dark, that is, the equivalent age of these flies compared to a culture kept always dark should be

\[ T = \frac{1}{5.7 + 2.8 \times 10^{-7}} \]

### TABLE I.

**Duration of Life at Various Intensities Calculated from**

<table>
<thead>
<tr>
<th>Meter candles</th>
<th>Observed</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>17.5</td>
<td>(17.5)</td>
</tr>
<tr>
<td>160</td>
<td>17.5</td>
<td>17.4</td>
</tr>
<tr>
<td>640</td>
<td>17.5</td>
<td>17.0</td>
</tr>
<tr>
<td>1,280</td>
<td>17.0</td>
<td>16.5</td>
</tr>
<tr>
<td>2,500</td>
<td>15.7</td>
<td>(15.7)</td>
</tr>
<tr>
<td>5,000</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>10,000</td>
<td>11.3</td>
<td>11.6</td>
</tr>
</tbody>
</table>

### TABLE II.

<table>
<thead>
<tr>
<th>Days at 10,000 meter candles</th>
<th>Observed</th>
<th>3</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days in dark</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Average total duration of life</td>
<td>13.5</td>
<td>8.0</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>14.0</td>
<td>7.8</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Equivalent age = \( \frac{3}{3.9} \times 13.5 = 10.6 \)

\( \frac{3}{3.9} \times 13.5 = 10.6 \) days, and they should therefore live about 3 days after placing in the dark. Actually, they lived nearly 5 days. The experiment shows, therefore, that the light produces an effect other than the mere acceleration of the normal "aging rate" and that this effect is not completely reversible, since in case of complete reversibil-
ity or recovery the short exposure would have had no effect on the total
duration of life.

It was noted previously that the upper temperature limit for con-
tinued growth of these cultures, 27°C., is surprisingly low and it seemed
possible that this might be due to the fact that the experiments were
made in the dark. It was found, however, in experiments in which
the cultures were exposed to diffuse daylight, through glass, that the
upper temperature limit remained the same.

SUMMARY.

The duration of the larval and imago periods of *Drosophila* cultures
which had been previously grown in the dark for 200 generations has
been determined at various light intensities.

1. The duration of the larval period is shortened slightly at intensi-
ties around 2,500 meter candles, but becomes increasingly longer at
higher intensities. The larvae are killed by continuous exposure to
light of 7,000 to 10,000 meter candles.

2. The pupae are killed at intensities greater than 5,000 meter
candles.

3. Above 1,000 meter candles the duration of the imago period is
rapidly shortened.

4. The duration of life of the imago at different intensities of illu-
mination can be quite accurately predicted by assuming that the light
produces an independent "rate of aging" which is proportional to the
intensity of the light.

5. The result of short exposure of the imago shows that light does
not merely accelerate the normal "rate of aging," and also that the
effect is only partially reversible.

Diffuse daylight does not affect the upper temperature limit of
growth.