THE EFFECT OF ILLUMINANCE ON THE LETHAL TEMPERATURE IN THE DRONE FLY, ERISTALIS TENAX

WILLIAM L. DOLLEY, JR., AND JOHN D. WHITE

Department of Biology, University of Buffalo, Buffalo, N. Y.

Although heat injury in organisms has aroused the interest of many able physiologists, the mechanisms involved are still unknown. According to Bělehrádek (1935), various authors have suggested that heat death is due to (1) the coagulation of proteins, (2) the destruction of enzymes, (3) asphyxiation, caused by the inability of the oxygen supply to keep pace with the needs caused by increased metabolic rate, (4) intoxication produced by certain products, and (5) a change in the physical state of lipids.

Recently a study of this phenomenon in the drone fly, *Eristalis tenax,* was begun and as a result additional facts have been discovered. According to Dolley and Golden (1947), in an illuminance of 700 foot candles, the temperature at which Eristalis dies, the lethal temperature, depends upon the sex and age of the flies. The lethal temperature is higher for females than for males of the same age, and it is higher for young flies than for old flies. Moreover, according to these authors, there is a correlation between the lethal temperature and the reversal temperature in an illuminance of 700 f. c. In general, the higher the reversal temperature, the higher the lethal temperature.

Since nothing was known about the relation between the lethal temperature and illuminance in any organism, a study of this relation in Eristalis was made. The results obtained are presented in this paper.

Materials and Methods

The apparatus and methods used were those described previously (Dolley and White, 1951) with the following exceptions: the same lamp, that used in all the illuminances but one mentioned in the previous paper, was employed for all illuminances used in this work; the dark chamber (Fig. 1, B, previous paper) was not used; the slide, a, was not raised; and the procedure was modified as described in the three following paragraphs.

The temperature at which the flies died in a known illuminance was determined. This was done for 270 males and for 270 females in each of the five illuminances: 250, 600, 800, 1200, and 1600 f. c.

Approximately thirty young flies of the same sex were placed in the light chamber, A (Fig. 1, previous paper). As the temperature rose, the flies becoming restless, crawled and flew about. Soon the animals, one by one, fell upon their backs, whirled around for a few moments, and then became quiet, except for a flexing and extension of the muscles of one or more legs, and extension and withdrawal of the proboscis. This movement continued for a brief interval. When all perceptible movement in a fly ceased, the temperature at which this occurred was recorded as the lethal temperature of this specimen. In quick succession the other flies died and their lethal temperatures were recorded.

Often certain flies crawled into a corner near the top of the chamber where the temperature was lower than at the bottom. When this occurred, the thermometer, d, placed in a hole near the bottom of the chamber was removed, and by means of a wire inserted through this hole the fly was dislodged. The thermometer was then replaced. After approximately 45 minutes all the flies had died. They were removed, the heating unit disconnected, and the box was allowed to cool. The heating unit was again connected, and, when the temperature in this chamber had again become about 28° C., another lot of flies was placed in the chamber and the process repeated.

Although the temperature throughout the light chamber was probably not uniform the lethal temperatures measured were very close to those where the flies were at a given instant. The thermometer measured the temperature on the floor of the chamber. During most of the periods of exposure the flies were in contact with this floor.

Results

The results obtained are given in Figure 1 and Table I.

The mean temperatures in degrees centigrade at which the male flies died are given in Table I. The differences between the means at 250 and 600, 600 and 800, 800 and 1200, 1200 and 1600 f. c. and at 250 and 1600 f. c., are respectively: 8 +, less than 1, 1 +, 10 +, and 1 + times the standard errors of the differences. This means that the odds against the occurrence from chance of these differences are, respectively: over 400,000,000,000; less than 1; 3; over 400,000,000,000; and 13 to 1. Evidently the differences between the means at 250 and 600 and at 1200 and 1600 f. c. are definitely significant, while the differences between the means at 600 and 800, 800 and 1200, and at 250 and 1600 f. c., are not significant.

Therefore, it is clear that as the illuminance was increased from 250 to 1600 f. c., the mean temperatures at which the male flies died decreased to a minimum at 600 f. c. and then increased to a maximum at 1600 f. c., and this mean temperature at 1600 f. c. was approximately the same as that at 250 f. c.

The mean temperatures in degrees centigrade at which the female flies died are given in Table I. The differences between the means at 250 and 600, 600 and 800, 800 and 1200, 1200 and 1600, and at 250 and 1600 f. c., are, respectively: 9 +, 1 +, 2 +, 10 +, and less than 1 times the standard errors of the differences. This means that the odds against the occurrence from chance of these differences are, respectively: over 400,000,000,000; 16; over 267; over 400,000,000,000; and less than 1 to 1. Consequently, the differences between the means at 250 and 600 and at 1200 and 1600 f. c. are definitely significant; the difference between the means at 800 and 1200 f. c. is probably significant; and the differences between the means at 600 and 800 and at 250 and 1600 f. c. are not significant.

As the illuminance was increased from 250 to 1600 f. c., the mean temperatures at which the female flies died decreased to a minimum at 600 f. c., and then increased to a maximum temperature at 1600 f. c., about the same as that at which the flies died in 250 f. c.

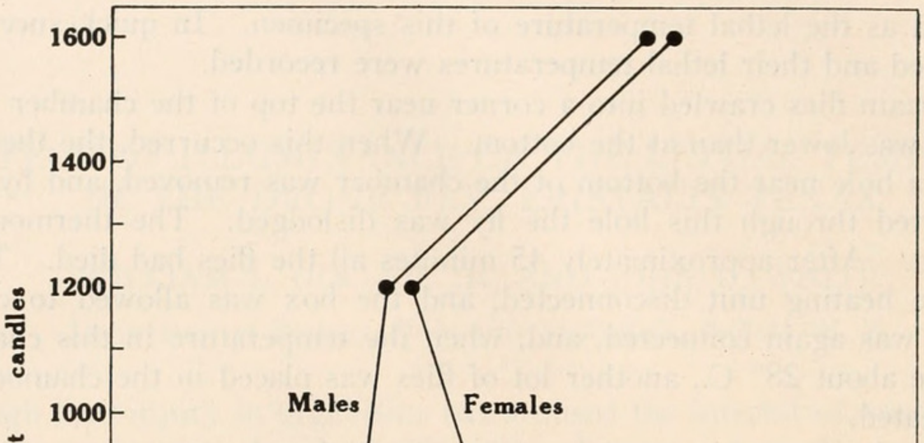

FIGURE 1. Graph showing the effect of illuminance on the temperature at which Eristalis dies. Note that the means of the lethal temperatures decrease to a minimum at 600 f. c., and then increase to a maximum at 1600 f. c. See text and Table I.

TABLE I

The effect of illuminance on the temperature at which Eristalis dies. See text.

Illuminance in foot candles	Sex	Mean temperature in degrees centigrade ± standard error	Standard deviation ± standard error
250	Male	52.956 ± .194	3.193 ± .137
	Female	53.811 ± .182	2.984 ± .128
600	Male	50.889 ± .162	2.658 ± .114
	Female	50.661 ± .152	2.50 ± .11
800	Male	50.994 ± .141	2.310 ± .099
	Female	52.089 ± .157	2.581 ± .111
1200	Male	51.222 ± .140	2.307 ± .099
	Female	51.428 ± .150	2.457 ± .106
1600	Male	53.417 ± .177	2.910 ± .125
	Female	53.65 ± .16	2.618 ± .113

The differences between the means of the two sexes in the various illuminances (250, 600, 800, 1200, and 1600 f. c.) are, respectively: 3 +, 3 +, 5, 1, and less than 1 times the standard errors of the differences. This means that the odds against the occurrence from chance of these differences are, respectively: over 726, over 1483, over 1,744,000, 2, and less than 2 to 1. It is obvious that the differences between the means of the two sexes in illuminances of 250, 600, and 800 f. c. are significant, while the differences in the other two illuminances are not significant. The female flies died at higher temperatures, therefore, than did the male flies in illuminances of 250, 600, and 800 f. c. This is in accord with the work of Dolley and Golden (1947).

Great confidence is felt in the results reported in this paper and in the preceding one on reversal temperatures. Essentially similar results were obtained in extensive preliminary experiments which were discarded because sources of light open to possible criticism were used.

As stated previously, Dolley and Golden (1947) reported a correlation between the reversal and lethal temperatures in Eristalis, in an illuminance of 700 f. c., the higher the reversal temperature, the higher the lethal temperature. This statement also holds true for illuminances of 250, 600, 1200, and 1600 f. c., but apparently does not at 800 f. c.; as the illuminance increased from 600 to 800 f. c., the mean temperature at which the flies reversed decreased (Fig. 2, Dolley and White, 1951), but there was no corresponding decrease in the mean temperature at which the flies died in these two illuminances (Fig. 1, this paper).

The results obtained are not due to differences in relative humidity or in the duration of exposure of the insects to heat. There was variation in these factors in the nine or more experiments performed at various times during three years on flies of each sex in each of the illuminances used. Yet when the values of these factors in all of the experiments are compared, there is no significant difference in the average value of these factors in the various illuminations.

Discussion

The results presented in this paper show that as the illuminance rises from 250 to 1600 f. c., the lethal temperature of Eristalis decreases to a minimum and then increases to a maximum. In other words, as the light energy to which the flies are exposed increases, the resistance of the organisms to heat decreases to a minimum and then rises to a maximum. These results are in harmony with the results reported by certain investigators on the physical changes induced by heat in certain organisms and in certain important constituents of organisms: proteins, lipids, and enzymes. According to Heilbrunn (1943, p. 78), in some types of protoplasm, as the temperature is raised, the protoplasmic viscosity increases and then decreases, *i.e.*, it goes through a maximum. Moreover, according to Ostwald (1913), as the temperature of a weak albumin sol rises, the viscosity first decreases, then sharply increases to a maximum, and then decreases again. The same author maintains that as the temperature of a lipid, isobutyric acid, in water, rises, the viscosity decreases slightly, then rises to a maximum, and then decreases. According to Sizer (1943), if enzyme reactions are exposed to rising temperature, the rate of the reactions increases to a maximum and then decreases.

Consequently, the curves describing the results given in this paper are strikingly similar in some respects to those curves reported previously by other investigators recording the viscosity changes in certain proteins, lipids, types of protoplasm, and changes in rates of certain enzyme reactions, on exposure to rising temperature. The significance of this similarity awaits further work. The results presented for Eristalis do not seem to lend support to the asphyxiation or intoxication theories listed by Bělehrádek, but they are in harmony with the other three theories mentioned previously. Heat death in Eristalis, therefore, may be due to any one, two, or three of the following: viscosity changes in certain proteins and lipids, and change in rate of reactions of certain enzymes.

Summary

1. Observations were made on 2700 young flies in ascertaining the temperature at which Eristalis dies in illuminances of 250, 600, 800, 1200, and 1600 f. c.

2. As the illuminance increases from 250 to 1600 f. c., the mean temperatures at which the male and female flies die decrease to a minimum at 600 f. c., and then increase to a maximum temperature at 1600 f. c., about the same as that at which they die in 250 f. c.

3. In illuminances of 250, 600, and 800 f. c., the temperature at which Eristalis dies depends upon the sex of the fly. The females die at higher temperatures in these illuminances than do the males. This sexual difference is not present in illuminances of 1200 and 1600 f. c.

4. There is a correlation between the reversal and lethal temperatures in Eristalis in illuminances of 250, 600, 1200, and 1600 f. c. The higher the reversal temperature, the higher the lethal temperature. This correlation does not apparently exist in an illuminance of 800 f. c.

5. As the light energy to which Eristalis is exposed increases, the resistance of the organisms to heat decreases to a minimum and then rises to a maximum. Consequently, the curve describing these events resembles greatly those curves reported previously by other investigators recording the viscosity changes in certain proteins, lipids, and protoplasms, and changes in rates of certain enzyme reactions, on exposure to rising temperature.

LITERATURE CITED

Bělehrádek, J., 1935. Temperature and living matter. Borntraeger. Berlin.

Dolley, W. L. Jr., and L. H. Golden, 1947. The relation between the lethal and reversal temperatures in the drone fly, *Eristalis tenax*. *Anat. Rec.*, **99**: 117. (Abstract).

Dolley, W. L. Jr., and John D. White, 1951. The effect of illuminance on the reversal temperature in the drone fly, *Eristalis tenax*. *Biol. Bull.*, **100**: 84–89.

Heilbrunn, L. V., 1943. An outline of general physiology. W. B. Saunders Company, Philadelphia and London.

Ostwald, W., 1913. Colloids and their viscosity. *Trans. Far. Soc.*, **9**: 34–46.

Sizer, I. W., 1943. Effects of temperature on enzyme kinetics. Advances in Enzymology, **3**: 35–62.