# THE EFFECTS OF TEMPERATURE AND LIGHT ON LOCOMOTOR ACTIVITY OF THE AMERICAN COCKROACH *PERIPLANETA AMERICANA* L.

A THESIS

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# THE EFFECTS OF TEMPERATURE AND LIGHT ON LOCOMOTOR ACTIVITY OF THE AMERICAN COCKROACH *PERIPLANETA AMERICANA* L.

## INTRODUCTION

Constant environmental conditions of temperature and light are found only rarely in North Temperate terrestrial environments. Examples of such environments are afforded by the lower levels of the soil, the interior of trees and fallen logs, the deep portions of caves, and the accumulations of stored products. Hence, for that vast number of poikilothermic organisms who are subjected to diurnal variations in temperature and light, we can regard fluctuations in these parameters as "normal" and the absence of fluctuations as "abnormal." Yet, many experimental investigations on the effects of temperature and light on animal activities have failed to acknowledge the normality of fluctuating conditions and have been conducted under constant conditions with respect to these parameters (see: Bullock, 1955; Nicholson, 1934; Prosser, 1955; Uvarov, 1931; Wigglesworth, 1950).

Where the effects of constant versus alternating temperatures have been investigated, the evidence seems to indicate that constant conditions may tend to depress while fluctuating conditions accelerate various animal activities.

Uvarov (1931) and Cloudsley-Thompson (1953a) reported that fluctuations of temperature often accelerate the rate of development in insects. The hatching rate from cysts of the potato-root eelworm Heterodera rostochesis has been found to be higher under alternating temperature than under constant temperature (Bishop, 1956). Alternating temperatures have been correlated with an increase in metabolism in the cutworm larva Chlorizagrotis auxiliaris (Cook, 1927), the flour moth Ephestia kuehniella, the fruit fly Drosophila melanogaster (Gromadska, 1949), and the malarial mosquito Anopheles quadrimaculalus (Huffaker, 1942). A decrease in locomotor activity when kept at prolonged constant temperature has been shown in the millipedes Ophistreptus sp. and Oxydesmus platycereus (Cloudsley-Thompson, 1951) and the cockroach Periplaneta americana (Cloudsley-Thompson, 1953b). An increase in activity with alternating temperature has been observed in the slug Agriolimax reticulatus (Dainton, 1954) and the guppy Lebistes reticulatus (Morris, 1959).

Recent emphasis has been placed on studying the relationship between light conditions and diurnal rhythms (Brown, 1957; Bruce and Pittendrigh, 1957; Calhoun, 1944; Cloudsley-Thompson, 1952; Harker, 1958; Park, 1940; Welsh, 1938). Where light conditions affect diurnal rhythms, constant conditions tend to eliminate the rhythm while alternating conditions often engender a rhythm. Harker (1956) and Cloudsley-Thompson (1953b) have shown that the American cockroach Periplaneta americana exhibits a diurnal rhythm of activity correlated with periods of light and dark, the peak of activity occurring in the dark period. After a period of less than a week in conditions of constant light or dark, activity occurs at random intervals or tends to be constant. Thus, the "normal" diurnal rhythm of activity is broken under constant conditions of light or dark. Gunn (1940) and Mellanby (1940) observed this phenomenon in another species of cockroach, Blatta orientalis.

Since temperature and light normally vary together in environmental conditions, it is surprising that so few laboratory studies have been concerned with the interaction of the two. A few investigations have been conducted on the effects of temperature and light on diapause in insects (Lees, 1955), development of the diamond-backed moth (Atwal, 1955), mating behavior of oriental fruit fly (Roan, Flitters and Davis, 1954) and various insects (Uvarov, 1931), migratory behavior of locusts (Uvarov, 1931), and tropisms in insects (Fraenkel and Gunn, 1940). Park and co-workers (1931) found an apparent correlation between changes in temperature, light, and relative humidity and the change in activity of diurnal and nocturnal animals. The greatest activity of Ptinus tectus occured under conditions of both alternating temperature and light. These conditions most closely resembled the environmental conditions of the habitat of the animal (Bentley, Gunn and Ewer, 1941).

The purpose of the present study is (1) to determine the effects of constant and alternating conditions of temperature and light on the activity of the American cockroach Periplaneta americana and (2) to determine whether temperature and light are interacting factors that influence total activity per day. This information would supplement previous investigations on the effects of temperature and light on animal activity, and furthermore, add to our knowledge of the effects of constant versus alternating environmental conditions.

A definition of the term "activity" is desirable to avoid confusion. The term "activity" is often used by the field ecologist and experimental physiologist. The field ecologist, when describing an animal as being active, means that the animal can be found moving about, presumably in search of food, water, and mate, as opposed to resting. Where this behavior has been investigated in the laboratory, activity has usually been taken to mean locomotor activity because it is possible to obtain a measure of this phenomenon, and it necessarily accompanies the acquisition of food, water, and mate. Unless otherwise stated in this investigation, the term "activity" will mean locomotor activity.

A distinction between fluctuating and alternating temperatures will be made in this paper. The term "fluctuating" temperature will be used to refer to temperature variations as they occur in a natural environmental situation. In referring to the term "alternating" temperature, this term will mean a periodic change from a controlled high temperature to a controlled low temperature over a specified time period. This situation would be found primarily under laboratory conditions.

## MATERIALS AND METHODS

### Materials

The American cockroach *Periplaneta americana* L. is a member of the order *Orthoptera* and the family *Blattidae*. Members of this family can be recognized by their oval and depressed body shape, long slender antennae, partial concealment of the head by the pronotum, a backward projection of the mouth parts, and well developed running legs (Ross, 1956). The adult American cockroach is reddish brown in color, has well developed wings, and is quite large, measuring $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in length. This species, a native of Central America and Mexico, is cosmopolitan in distribution throughout the United States (Essig, 1938).

*Periplaneta americana* is nocturnal, commonly frequenting dark humid locations, and found only in limited numbers in the field. Most members of this species inhabit human dwellings and heated buildings, thus enabling them to thrive throughout the year (Ross, 1956).

The American cockroach develops by incomplete metamorphosis and completes its life cycle in approximately 21 months. The nymph stages are similar to the adults in general structure; however, they lack wings. Nymphs are extremely active but grow relatively slowly. Both adults and nymphs are omnivorous, eating a wide variety of plant and animal food (Belding, 1952). Animals were maintained in this laboratory on a diet of dog biscuits and water.

Nymphs of Periplaneta americana were selected as the experimental animal for the following reasons: (1) these animals were abundant and easily maintained; (2) they are subjected to environmental fluctuations of temperature; (3) a light engendered rhythm of activity has been demonstrated in these animals; (4) nymphs, though not sexually mature, are extremely active and relatively slow growing.

Cockroaches used in this study were part of a population inhabiting the basement of Norton Science Hall on the Emporia State Campus. The temperature of the basement, during the period of study, varied from 22° to 35°C. Although the cockroaches were subjected to the normal diurnal rhythm of photoperiod, the rhythm was occasionally interrupted when incandescent lights in the basement were left on during the evening hours.

Captured animals were maintained in the laboratory under room conditions (minimum-maximum temperatures of 18° to 32°C. and normal photoperiod) for periods of not less than two days nor longer than seven days prior to experimentation. The individuals used weighed from 0.5 to 1.3 grams and ranged from middle to late stages of nymphal development. Nymphs were maintained at constant experimental temperatures of 10° ± 1.0°C. or 20° ± 1.0°C. in two Labline refrigerated incubators. A Sargent incubator was used to maintain animals at a temperature of 30°C. Alternating temperatures were simulated by moving experimental animals from one temperature to another every 12 hours. Animals were placed in one of three conditions of light: constant light, constant dark, or alternating light and dark. Fourteen watt fluorescent lamps were used as a light source. Alternating photoperiod of 11 hours light and 13 hours dark were controlled by means of an electric timer switch. Conditions of constant dark were produced by placing the animals in a black plastic box. All experimental animals were maintained in approximately 100 per cent relative humidity as determined by an electric hygrometer. Animals were given an initial supply of food, and fresh water was added every third day.

The technique used to record activity of cockroaches was designed specifically to measure total activity over a 24 hour period. This differs from previous techniques which were designed to detect rhythms of activity throughout a continuous period (Cloudsley-Thompson, 1955). The method of determining activity involved the measurement of the amount of tracking by a cockroach on a smoked surface. Two types of apparatus were constructed for this determination: (1) a recording chamber in which experimental animals were allowed to move about; (2) a measuring device to determine the amount of movement by the animal.

The recording chamber, designed to house ten individuals, is shown in Plate I. The chamber is constructed of wood and plexiglass, into which grooves are cut for inserting a series of glass plates. The glass plates measure 6 inches by 6 inches and are smoked on one side by the means of a kerosene burner. A maze, constructed of cardboard and plastic, is placed on the smoked glass plate. This maze promotes a uniform pattern of animal movement over the plate. The front of the recording chamber is a removable sliding door. Small compartments are attached to this sliding door and an entrance to these compartments is made by boring holes in the door. Animals are placed in these compartments prior to each experimental run and contained there by a sliding aluminum strip. The door is attached to the recording chamber. Upon removal of the sliding aluminum strip, animals are able to move onto the smoked glass plate.

Plate II is an illustration of the measuring device. A light source, provided by a Viewlex slide projector, is directed on a tracked smoked glass plate. All light rays

Plate I. Activity recording device used to determine total activity per day. (a) Recording chamber; (b) Glass plate; (c) Maze; (d) Removable door; (e) Aluminum strip.

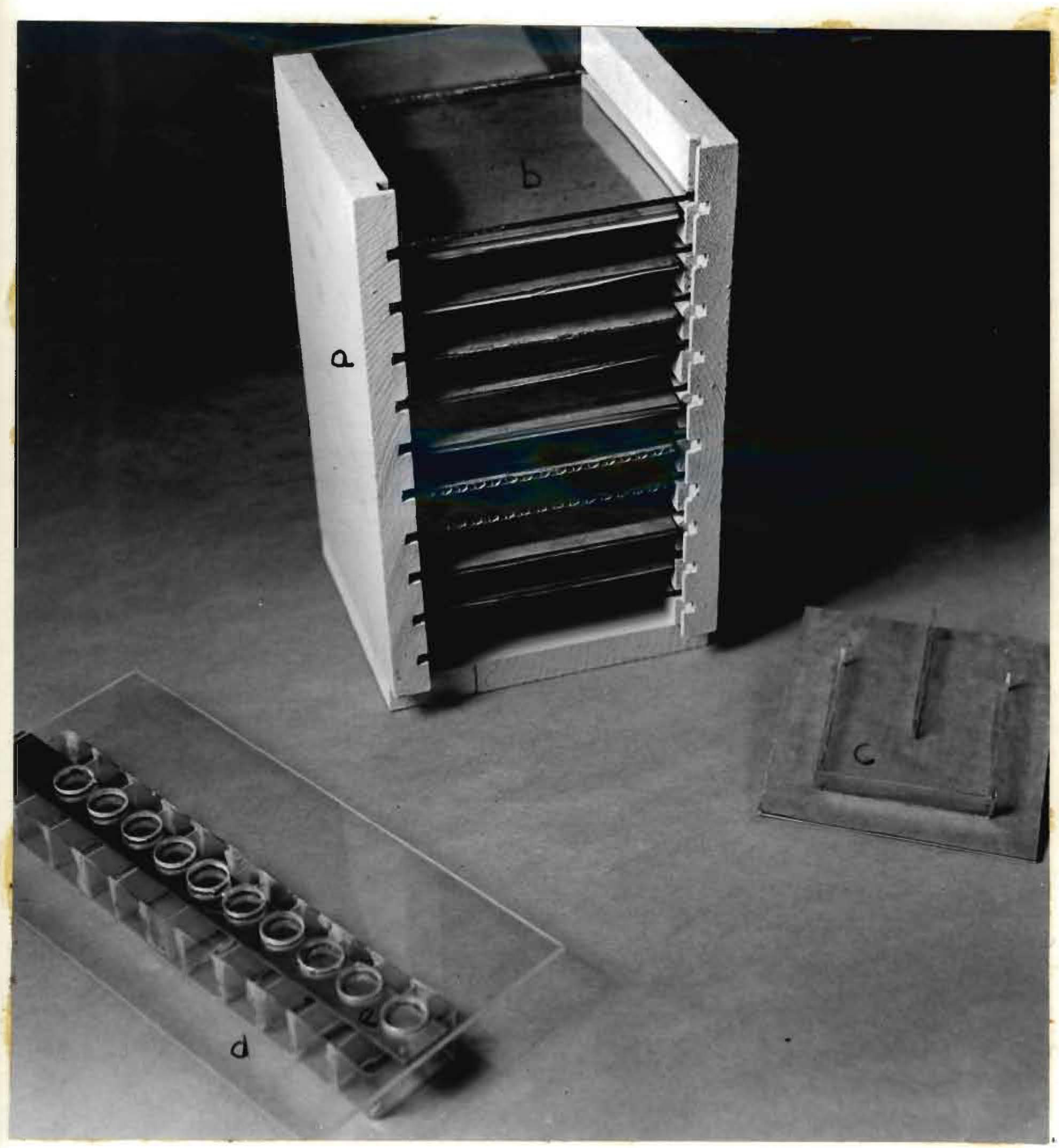
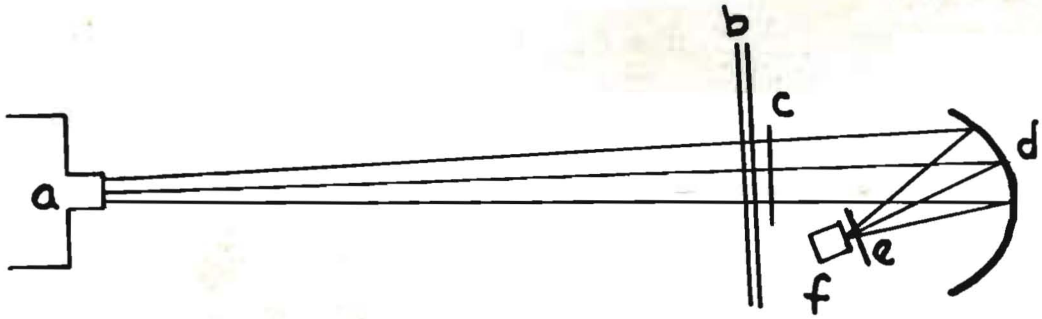

b
a
c
d
e

Plate II. Diagram of measuring device used to determine activity. (a) Viewlex slide projector; (b) Protective screen; (c) Smoked glass plate; (d) Spherical glass mirror; (e) Wire screen; (f) Weston light meter.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not striking the plate are absorbed by a dark protective screen constructed from a sheet of plywood. The light rays passing through the plate are collected by a 40 cm. spherical glass mirror. The spherical mirror focuses the light rays on the photosensitive surface of a Weston light meter. A screen, constructed of fine meshed screen wire, was placed between the spherical mirror and the light meter. This permitted light meter readings of 0-300 ft. candles. The amount of light passing through a plate is proportional to the amount of tracking on the plate.

Methods

Previous studies (Richards, 1958; Dehnel and Segal, 1956) have shown that Periplaneta americana can be maintained in the laboratory at temperatures from 10° to 30°C. Richards (1958) has reported that they were active within this temperature range. Therefore, 10°, 20°, and 30°C. were selected as the experimental temperatures. It should be noted, however, that individuals used in this experiment did not feed at 10°C. and activity was often depressed to the point of spasmodic movement of the legs.

Three hundred and fifty animals were randomly divided into 17 groups of 15 to 25 animals each. Cockroaches maintained at 10°C. were subdivided into three equal groups: (1) constant light; (2) constant dark; (3) and alternating light and dark. Animals maintained at 20° and 30°C. were subdivided in a similar manner. Eight groups of animals were placed at alternating temperatures of 10° to 30°C. and 20° to 30°C. Since Mellanby (1939) has shown that insects may acclimate to temperature conditions in less than 20 hours, it was necessary to determine the effect of the last 12 hours at a given temperature prior to recording. Cockroaches subjected to alternating temperatures of 10° to 30°C. were subdivided into four groups with respect to light and temperature during the 12 hours prior to recording; these groups are: (1) constant light and cold temperature, (2) constant light and warm temperature, (3) constant dark and cold temperature, and (4) constant dark and warm temperature. Animals subjected to alternating temperature of 20° to 30°C. were similarly divided into 4 temperature-light groups. All cockroaches, other than those taken directly from the basement habitat, were maintained under experimental conditions for a period of one week.

In recording activity three chambers, each containing ten animals, were placed in an incubator. A minimum of 30 minutes was allowed for the animals to become quiescent. At the end of this period, animals were allowed to move onto the smoked glass plates. All recordings of activity were made at 30°C. in constant light. The activity of control groups was recorded in constant dark at 30°C. and in constant light at 20°C. to determine the effect of temperature and light during recording. A relative humidity of 40 ± 10 per cent was maintained in the reading chambers using the proper concentration of $Mg(NO_3)_2$ (Wexler and Brombacher, 1951). To avoid possible diurnal rhythm effects, all measurements were made over a 24 hour period beginning at 7:00 to 10:00 a.m. Neither food nor water was provided during the period of recording.

The activity of each group was computed as a percentage of the most active group. The most active group was arbitrarily assigned a value of 100 per cent. Individual data were discarded if very low or very high values were obtained which were shown to be due to injury or death of the animal.

Activity data collected from animals maintained at 10°, 20°, and 30°C. were compared to determine the effects of temperature on activity at a given condition of light. The effects of constant light, constant dark, and alternating light and dark on activity at a given temperature were determined by comparing data collected from experimental groups maintained at each of these conditions. To determine the effect of temperature during the 12 hours prior to recording, the activity of groups maintained at a high temperature was compared with the activity of groups maintained at a low temperature.

Treatment of data

The statistical methods employed were as outlined in Johnson (1949). A mean percentage of activity for each experimental group was calculated. The *t* test was used to test the significance of the differences between the means. The *t* values obtained were applied to the *t* distribution table (Fisher and Yates, 1949) to determine the probability value. Probability values of $P < .05$ were considered statistically significant.

The activity data were plotted graphically by the use of the bar graph. The percentage of activity plotted for each group was the mean activity of the group.

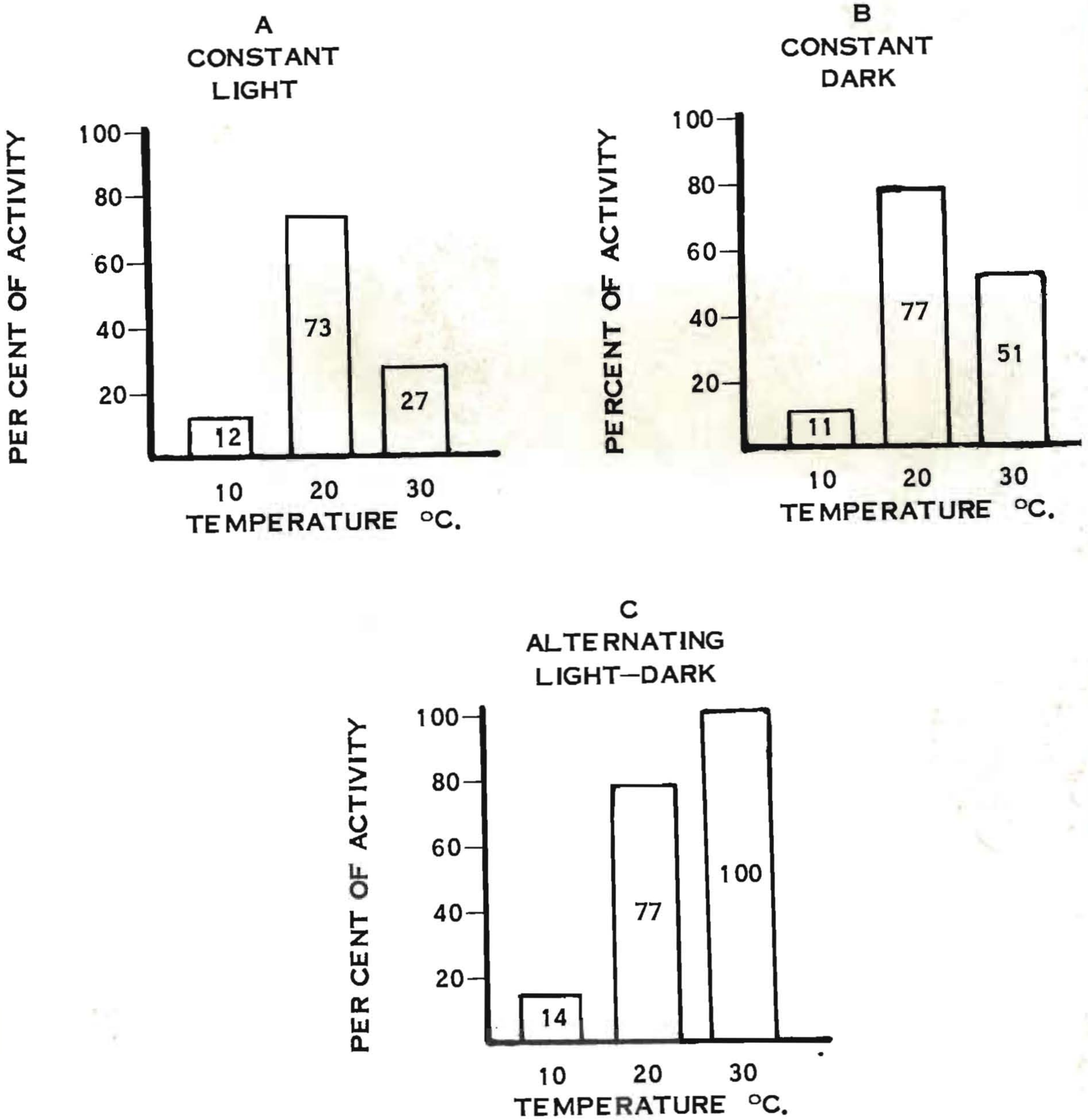
RESULTS

Effect of temperature on activity

Temperature is a primary factor in determining total activity of P. americana. When the total activity of animals maintained under conditions of alternating light and dark was measured at 30°C. it was found that as temperature increases activity increases. Total activity of three groups of animals, maintained for one week at temperatures of 10°, 20°, and 30°C. were measured at 30°C. and a comparison of percentages of activity for these groups is shown in Figure 1C. Over the size range measured, the 30°C. animals showed approximately 25 per cent greater activity than the 20°C. animals and 86 per cent greater than the 10°C. group. The animals maintained at 20°C. showed 63 per cent greater activity than the 10°C. individuals. A comparison of the variations from the mean with the t-distribution table showed the differences in total activity of animals maintained at 10°, 20°, and 30°C. to be significant at the 0.5 per cent level (Table I).

Under conditions of constant light and constant dark animals were found to be most active at 20°C. Figures 1A and 1B illustrate a comparison of percentages of activity for groups maintained at 10°, 20°, and 30°C. in constant light and constant dark for each temperature. Animals

Figure 1. Activity of P. americana maintained at 10°, 20°, and 30°C. and in (A) constant light, (B) constant dark, and (C) alternating light and dark. All recordings were made at 30°C. in constant light.


A
CONSTANT
LIGHT
PER CENT OF ACTIVITY
100
80
60
40
20
12
73
27
10
20
30
TEMPERATURE °C.
B
CONSTANT
DARK
PERCENT OF ACTIVITY
100
80
60
40
20
11
77
51
10
20
30
TEMPERATURE °C.
C
ALTERNATING
LIGHT—DARK
PER CENT OF ACTIVITY
100
80
60
40
20
14
77
100
10
20
30
TEMPERATURE °C.

| Temp. (°C.) | Light Cond. | 10° Const. L | 10° Const. D | 10° Alter. L-D | 20° Const. L | 20° Const. D | 20° Alter. L-D | 30° Const. L | 30° Const. D | 30° Alter. L-D |
|---|---|---|---|---|---|---|---|---|---|---|
| 10° | Const. L | | .0722 (P>.90) | .2630 (P>.80) | 7.3981 (P<.001) | | | 2.3209 (P<.05) | | |
| | Const. D | | | .3008 (P<.80) | | 5.1036 (P<.001) | | | 4.4651 (P<.001) | |
| | Alter. L-D | | | | | | 6.9801 (P<.001) | | | 11.0702 (P<.001) |
| 20° | Const. L | | | | | .3214 (P<.80) | .3660 (P<.80) | 5.5880 (P<.001) | | |
| | Const. D | | | | | | .0338 (P<.90) | | 2.1778 (P<.05) | |
| | Alter. L-D | | | | | | | | | 3.0433 (P<.005) |
| 30° | Const. L | | | | | | | | 3.0048 (P<.005) | 11.4206 (P<.001) |
| | Const. D | | | | | | | | | 5.6693 (P<.001) |
| | Alter. L-D | | | | | | | | | |

TABLE I. _t_ values and probability values for differences in total activity of groups of _P. americana_ kept at 10°, 20°, and 30°C. and in constant light, constant dark, and alternating light and dark at each temperature.

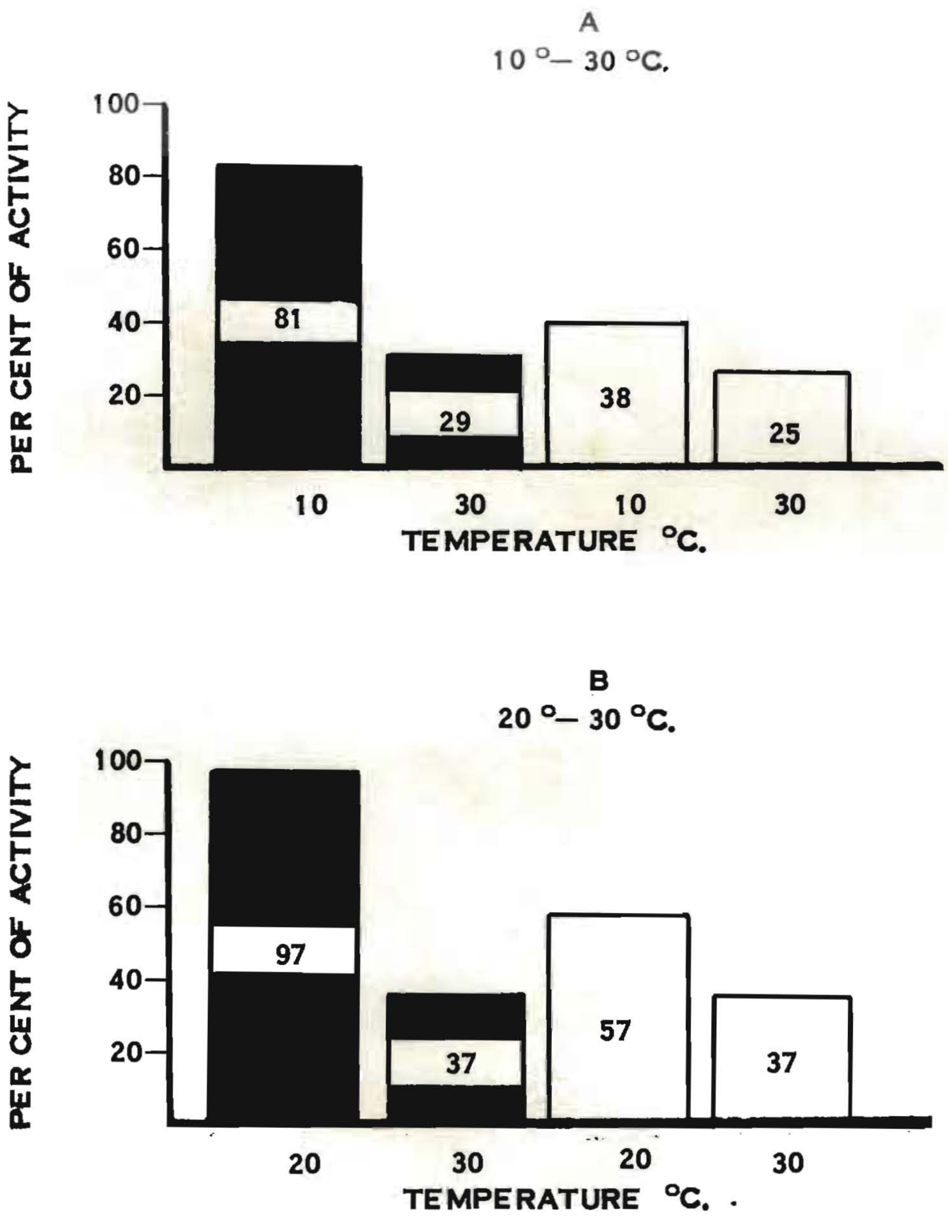
maintained at 20°C. showed approximately 66 per cent greater activity than the 10°C. group, regardless of light conditions. Only the 30°C. animals showed a differential response to being maintained under conditions of constant light and constant dark. When kept in constant dark the 30°C. animals showed 26 per cent less activity than the 20°C. group and 40 per cent greater activity than the 10°C. group. The activity of cockroaches maintained at 30°C. in constant light was 46 per cent less than 20°C. animals and 15 per cent greater than the 10°C. individuals. Animals maintained at 30°C. constant dark were approximately 50 per cent more active than those kept in constant light. All differences in total activity between the groups were statistically significant at the 5 per cent level (Table I).

Effect of the last 12 hours at a given temperature prior to recording

In determining the effect of alternating temperatures on activity, it appeared necessary to determine the effect of the temperature condition during the 12 hour period prior to recording. Figure 2 illustrates a comparison of the effects of the last 12 hours at low versus high temperature in conditions of constant light and constant dark for each temperature. At alternating temperatures of 10° to 30°C. animals kept in constant dark were 52 per cent more active

Figure 2. Activity of *P. americana* maintained at alternating temperatures of (A) 10° - 30°C. and (B) 20° - 30°C. and in both situations, the last 12 hours in dark-cold, dark-warm, light-cold, and light-warm. All recordings were made at 30°C. in constant light.

□ constant light ■ constant dark


A
10 °– 30 °C.
PER CENT OF ACTIVITY
100
80
60
40
20
81
29
38
25
10
30
10
30
TEMPERATURE °C.
B
20 °– 30 °C.
PER CENT OF ACTIVITY
100
80
60
40
20
97
37
57
37
20
30
20
30
TEMPERATURE °C.

when maintained in the cold (10°C.) for the last 12 hours than those maintained in the warm (30°C.). In constant light, animals at 10°C. for the last 12 hours showed 13 per cent greater activity than animals at 30°C. for the last 12 hours. Differences between the two groups maintained at alternating temperatures of 10° to 30°C. in constant dark were statistically significant at the 0.1 per cent level, while differences between those groups kept at the same temperature in constant light were not statistically significant (Table II).

Similar results were obtained when animals were subjected to alternating temperatures of 20° to 30°C. Animals kept in the dark-cold prior to measurement were 60 per cent more active than those kept in the dark-warm, while those kept in light-cold showed 20 per cent greater activity than those kept in light-warm. Differences between the two groups maintained in constant dark were statistically significant at the 0.5 per cent level, while differences between those groups kept in constant light were not statistically significant (Table II).

Effect of light on activity

Figure 3C illustrates the effect of light on total activity of a laboratory population of Periplaneta americana kept at a temperature (30°C.) approximating that of the

Table II. *t* values and probability values for differences in total activity of groups of *P. americana* kept at alternating temperatures of 10°-30° and 20°-30°C. and in both situations, the last 12 hours at dark-cold, dark-warm, light-cold, and light-warm.

| Fluct. Temp. (°C.) | Cond. of last 12 hr. | 10°-30° Dark-Warm | 10°-30° Light-Warm | 20°-30° Dark-Warm | 20°-30° Light-Warm |
|---|---|---|---|---|---|
| 10°-30° | Dark-Cold | 4.4049 (P<.001) | | | |
| | Light-Cold | | .8484 (P<.50) | | |
| 20°-30° | Dark-Cold | | | 3.3560 (P<.005) | |
| | Light-Cold | | | | .9378 (P<.40) |

natural habitat. Alternating light and dark (11-13 hr.) resulted in increased activity when compared with either constant light or constant dark. If values are compared it is seen that total activity has increased in the alternating light and dark group by 49 per cent over that of the constant dark group, and 73 per cent over that of the constant light group. These differences in activity are statistically significant at the 0.5 per cent level (Table I).

Other experiments with the same light conditions but different temperatures (10° and 20°C.), demonstrate the significance of temperature in determining the effect of light conditions on total activity. Light conditions have no distinguishable affect on activity when animals are maintained at 10° and 20°C. (Figures 3A and 3B). With respect to the most active group, these animals showed approximately 11 per cent activity at 10°C. and 70 per cent activity at 20°C. All differences in activity within both the 10° and 20°C. groups were not statistically significant (Table I).

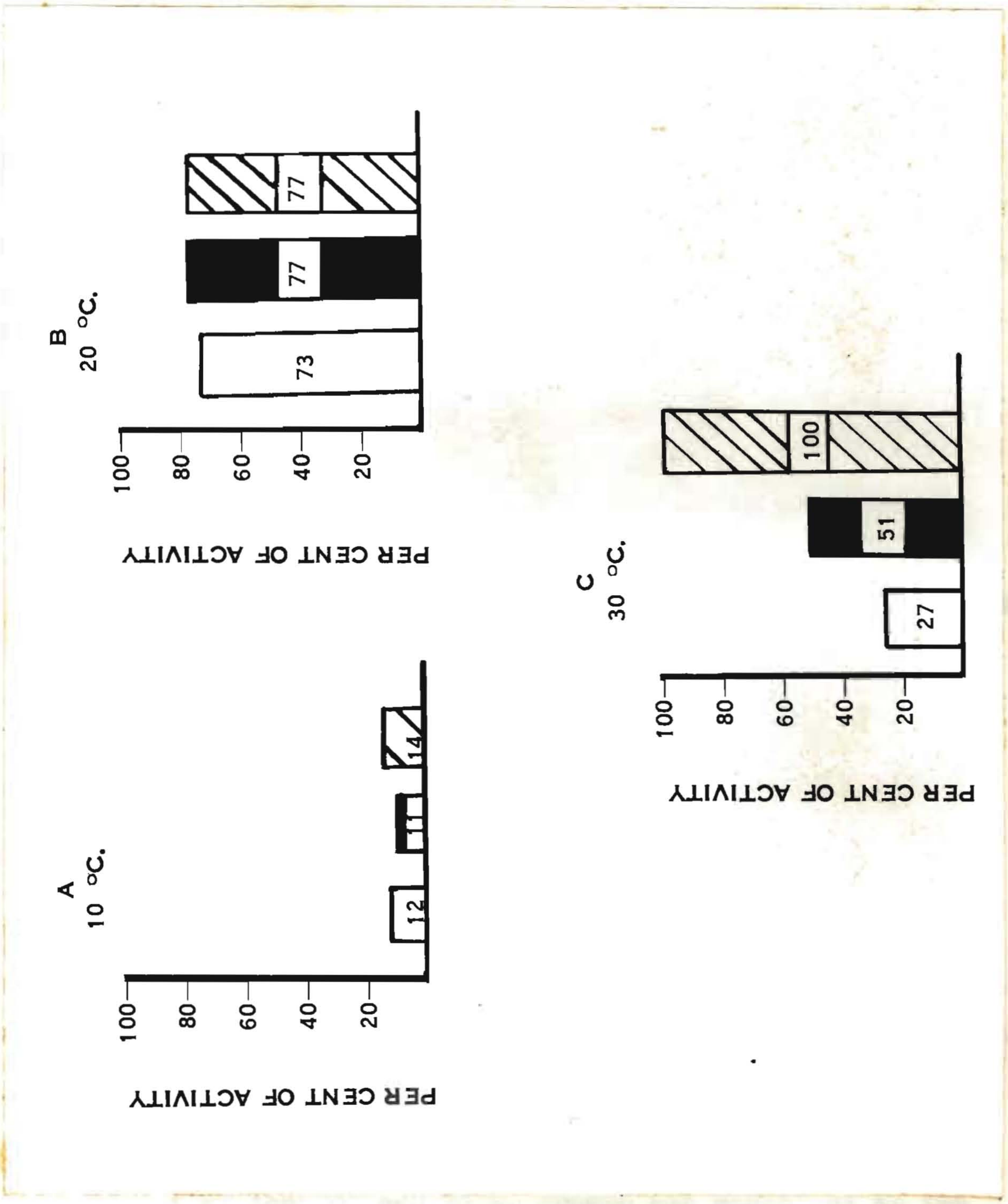
<u>Effects of temperature and light on activity</u>

Activity of cockroaches maintained under various conditions of temperature and light is shown in Figure 3. The greatest activity occured when animals were maintained at 30°C. in alternating light and dark. This group showed

Figure 3. Activity of *P. americana* maintained at (A) 10°, (B) 20°, and (C) 30°C. and in constant light, constant dark, and alternating light and dark. All recordings were made at 30°C. in constant light.

☐ constant light ■ constant dark

▨ alternating light and dark



A
10 °C.
B
20 °C.
C
30 °C.
PER CENT OF ACTIVITY
100
80
60
40
20
12
11
14
73
77
77
27
51
100

25 per cent greater activity than 20° animals kept in constant light, constant dark, or alternating light and dark, 50 per cent greater activity than 30°C. animals kept in constant dark, and 75 per cent greater activity than 30°C. animals kept in constant light. The 10°C. animals, regardless of light conditions, were the least active group, being approximately 89 per cent less active than the most active group.

Effects of other variables on activity

Size, within the weight range of 0.5 to 1.3 grams, appeared to have no affect on total activity. Total activity was measured for groups of 10 animals each maintained at 10°, 20°, and 30°C. and in constant light, constant dark, and alternating light and dark for each temperature. Under these conditions, weight had no apparent effect on total activity.

Temperature conditions during recording appears to influence the degree of total activity in the 20° and 30°C. animals, but not that of 10°C. animals. The activity of nine groups of 10 animals each was measured at 20°C. in constant light. The values obtained were compared with values obtained from animals measured at 30°C. in constant light. Activity of the 20° and 30°C. groups was decreased at the lower temperature, but differences between groups and within groups were similar to those when measured at the higher temperature.

Light conditions during recording appear to have no affect on total activity. Control groups of animals were recorded at 30°C. in constant dark. These animals showed no significant difference in activity from those groups recorded at the same temperature in constant light.

DISCUSSION

Effect of temperature on activity

Body temperatures are determined mostly by environmental temperatures for poikilothermal animals, and there is evidence that their rates of locomotion and other activities are governed largely by the direct influence of temperature. Under the conditions of this study it was found that temperature was a primary factor in determining daily activity in P. americana. In normal conditions of alternating light and dark, an increase in temperature resulted in an increase in activity (Figure 1C). However, in abnormal conditions of constant light or dark, activity at the higher temperature was depressed (Figures 1A and 1B).

Richards (1958) has investigated the effect of temperature on other bodily activities ($O_2$ consumption, heart beat, running speed, and wing frequency) in this same species. He found that in all cases as temperature increases the rate of these activities increases. Similar responses to temperature by insects have been shown in many widely divergent groups and are well documented in reviews on this subject by Gunn (1942), Nicholson (1934), and Uvarov (1931).

Temperature appears to have only a weak effect on orientation responses of P. americana (Gunn, 1935; Gunn and

Cosway, 1938) and fluctuations in temperature do not appear to have any influence on the diurnal rhythm of activity of this species (Cloudsley-Thompson, 1953b). Therefore, the influence of temperature on total activity may be of considerable ecological significance in determining habitat selection and geographical distribution. Whether this is the case, however, could be established only by a detailed field investigation.

<u>Effect of the last 12 hours at a given temperature prior to recording</u>

In determining the effect of alternating temperatures on total daily activity, it would appear necessary to determine the effect of temperature conditions during the 12 hours prior to recording. It was found that prior temperature conditions were important in determining the effect of alternating temperatures in *P. americana*. Animals maintained in the cold (10° or 20°C.) during the 12 hours prior to recording were more active than those groups kept in the warm (30°C.) when measured at 30°C. (Figures 2A and 2B). This phenomenon has also been observed in this laboratory by White (unpublished thesis) while investigating the rate of thermal acclimation in the garden slug *Limax flavus*. However, no mention of this response has been made in the literature reviewed.

There are several possibilities which might explain the cause of this phenomenon. First, it seems possible that the response to different temperature conditions prior to recording is due to short term acclimation as expressed by a change in activity of these animals. In the relatively few investigations concerning time course of acclimation for terrestrial poikilotherms, acclimation appears to be complete in one day or less. Mellanby (1939, 1954), investigating the effects of acclimation with respect to chill-coma temperature and thermal death point in insects, reported that acclimation occurred within 20 hours. Colhoun (1954) observed that the German cockroach _Blatella germanica_ showed acclimation to chill-coma temperature in one day. Acclimation with respect to increased activity in _P. americana_ is not clearly understood. Animals kept at constant 10°C. did not show increased activity when measured at 30°C., whereas those kept at alternating 10° to 30°C. showed increased activity when taken from 10°C. and measured at 30°C. However, animals kept at constant 10°C. were notably depressed and did not feed. It seems possible that the failure of these animals to show acclimation may have been due to the effects of starvation on activity.

A second possibility may be that activity was increased in response to rising temperatures. Animals kept at 30°C. for the last 12 hours and measured at 30°C. would not be subjected to temperature changes, whereas, animals kept at 10° or 20°C. and measured at 30°C. would be subjected to rising temperatures. Thus, the increase in activity of animals kept for the last 12 hours at a low temperature may be due to the temperature change per se. Dainton (1954), using the slug Agriolimax reticulatus, found that increasing temperatures above 21°C. and decreasing temperatures below this point caused an increase in locomotor activity. She attributed this increase in activity to changing temperature.

Due to the apparent importance of temperature conditions prior to recording, it was impossible to determine the effect of constant versus alternating temperature on activity.

## Effect of light on activity

Numerous investigators (Cloudsley-Thompson, 1952; Harker, 1958; Calhoun, 1944; Park, 1940; Welsh, 1938) have demonstrated that light conditions influence periods of animal activity. These investigations emphasize the importance of light conditions in initiating activity. Using a different approach to the problem of light effects on activity, I have found that light conditions, in combination with temperature, may effect total activity per day. Light had no apparent effect on activity when animals were kept at 10° and 20°C. but has a significant effect when animals were kept at 30°C. In alternating light and dark 30°C. animals were approximately twice as active as those kept in constant dark, and three times as active as those kept in constant light (Figure 3C).

The results obtained were in part contrary to those reported by Gunn (1940) and Harker (1956). In investigating the effects of light and temperature on activity in Blatta orientalis, Gunn states that "it is surprising to find that light had little, if any, effect on the total activity per day." Harker also reports this phenomenon in P. americana. However, descrepancies between this investigation and those by Gunn and Harker might be expected since: (1) Gunn was working with another species kept at a temperature of 25.5°C.; (2) Harker, though working with the same species, made no attempt to maintain constant temperature conditions.

Effect of temperature and light on activity

Several investigations indicate that temperature and light may act together in regulation of animal behavior (Park et al., 1931; Roberts, 1942; Uvarov, 1931). Generally, these investigations have shown that the reaction to light may be reversed or prevented when animals are subjected to temperatures above or below certain levels. The interaction of temperature and light appears to affect total locomotor activity in *P. americana* in this manner. At temperatures of 10° and 20°C. light conditions seem to have no affect on daily activity (Figures 3A and 3B). Whereas, at a temperature of 30°C. light conditions play a critical role in determining activity (Figure 3C). Since both temperature and light normally vary together in an environment, it is not surprising to find these two factors are interrelated in influencing a complex behaviorial phenomenon such as activity.

The interaction of temperature and light, as in the case of most interacting factors, depends on the relative as well as the absolute values for each factor. Under the conditions of this experiment it was not possible to accurately determine the relative interaction of temperature and light. More specifically designed studies will be necessary to fully understand this interaction.

Further evidence of the interaction of temperature and light may be seen by comparing the activity of experimental animals with that of animals collected from the natural habitat. It was found that 30°C. animals kept in alternating light and dark most closely resembled animals taken from the natural population. This is not surprising since these experimental conditions of temperature and light are similar to the environmental conditions of the natural population (minimum-maximim temperatures of 22° to 35°C. and a normal photoperiod).

SUMMARY

1. A quantitative method of recording total locomotor activity per day has been described.

2. Activity has been studied in the American cockroach, Periplaneta americana, that have been maintained at experimental temperatures of 10°, 20°, and 30°C. and in constant light, constant dark, and alternating light and dark at each temperature.

3. In normal conditions of alternating light and dark, 30°C. animals were 23 per cent more active than 20°C. animals, and 86 per cent more active than those kept at 10°C.

4. 30°C. animals kept in alternating light and dark showed 49 per cent greater activity than groups kept in constant dark, and 73 per cent greater activity than animals kept in constant light. At low temperatures (10° and 20°C.) there was no statistical difference in activity between groups kept in the 3 light conditions.

5. When maintained at alternating temperatures of 10° to 30°C. and 20° to 30°C. and in constant light or dark, animals kept in the cold (10° and 20°C.) for the last 12 hours were more active than those kept in the warm (30°C.). These data suggest that the immediate thermal history of an organism may be of primary importance in determining

subsequent locomotor activity and possibly other activity rate measures. Future studies certainly cannot neglect this factor.

6. Within the weight range of 0.5 to 1.3 grams there was no statistical differences in activity within and between experimental groups.

7. The importance of temperature, as a factor which may be of ecological significance in determining habitat selection and geographical distribution, is discussed.

8. The interaction of temperature and light has been shown to be important in determining locomotor activity, however, the data are insufficient to determine the relative significance of each in the interaction.

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