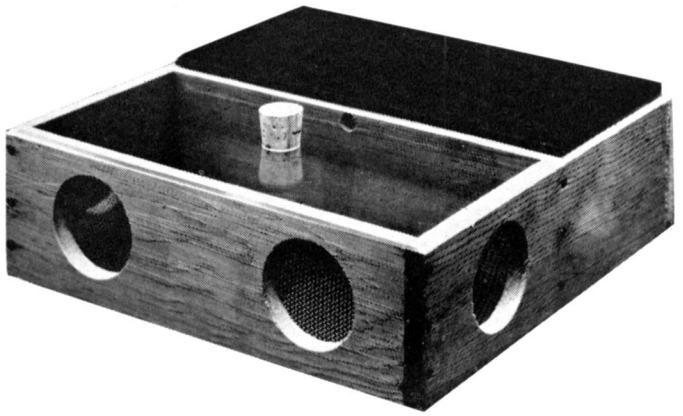
THE COCKROACH TO AVOID



"Choice box" for testing the repellency of insecticides to cockroaches. Back half of box is covered with fiberboard, creating preferred dark refuge for cockroaches. However, repellent insecticides will result in some of the insects learning to avoid the dark area before picking up a lethal dose.

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THE ABILITY OF INVERTEBRATES to learn (that is, the ability of the individual to modify its behavior as the result of experience) has been investigated extensively by animal behaviorists, psychologists, and others. Learning has been demonstrated in species as far down the evolutionary scale as the turbellarians (small marine worms) and it apparently reaches its peak among the octopuses. Using electric shock for punishment and food for reward, scientists have been able to train the octopus to distinguish between such various shapes as a square and a diamond, the same shape rotated through 45 degrees, or between a rectangle shown vertically and horizontally. Many such distinctions are made within 20 or 30 trials, and once having been learned, are retained for several weeks.

Greatest capacity

Among insects, bees and ants have shown the greatest capacity for learning. The honey bee does not have the octopus' ability to distinguish between relatively simple figures, but can distinguish between more complex forms as well as colors. Hymenopterous parasites reared in the laboratory have been trained to associate color with the presence of insect hosts. This has possible economic applications.

This is a report of studies of the ability of cockroaches to learn to avoid insecticide deposits after a number of initial contacts. This has been considered a principal factor affecting control, and it should influence the selection of insecticides and the manner of their application.

More resistant

Cockroaches learn less rapidly, forget more easily, and are more resistant to change in their learned behavior when conditions are altered than are bees or ants. Nevertheless, they have been popular subjects of investigation for over a half century, and three of the four common household species shown in photos have been investigated repeatedly. Electric shock has been the usual method used to provide punishment, and a dark enclosure with or without food, has served as the reward. As in the case of higher animals, cockroaches learn most rapidly in situations of some biological significance, such as learning the most direct route through a maze leading from a broad illuminated runway to a narrow dark place of refuge. What they learn is retained for a long time—as long as a month or more—after the insects are removed from the maze.

Seeking darkness

The instinct of the cockroach to seek dark seclusion when exposed to light is a characteristic that has been utilized frequently in the study of cockroach learning. The cockroach is placed in an elongated illuminated box, one end of which is enclosed to form a dark area in which the insect will seek refuge. The floor of the dark area consists of an electrified grid. Training of the insect is considered complete when it returns to the light area without receiving an electric shock some standard number of times. Sometimes a Y-tube with one arm electrified is substituted for the box.

Previous research

Research psychologists have reported in previous studies that adult male and female American cockroaches, *Periplaneta americana*, required from five to 32

DIFFERENCE IN PERFORMANCE OF INSECTICIDES USED AGAINST GERMAN COCKROACHES IN APARTMENTS OF 'SIMPLE' AND 'COMPLEX' ENVIRONMENT

Insecticide*	Number of apartments	Original number trapped per apt.	Avg. % survival†	
			1 month	3 months
A. Apartments with simple environment				
Boric acid	10	256	0.05	0.00
Baygon 1%	10	189	0.63	0.32
Diazinon 1%, dichlorvos 0.2%	10	46	0.94	0.22
B. Apartments with complex environment				
Boric acid‡	12	24	0.3	0.0
Baygon 1%	12	17	68.0	131.3
Diazinon 1%	12	7	11.2	21.0

* The boric acid (dust) was applied with Getz Guns (1 lb/apt), the liquids with compression sprayers (1 qt/apt).

† $\frac{\text{Avg no/apt after treatment}}{\text{Avg no/apt before treatment}} \times 100$

‡ An average of 0.25 pint of Baygon 1% emulsion was also applied per apartment in limited areas in kitchens and bathrooms.

LEARNS

INSECTICIDES

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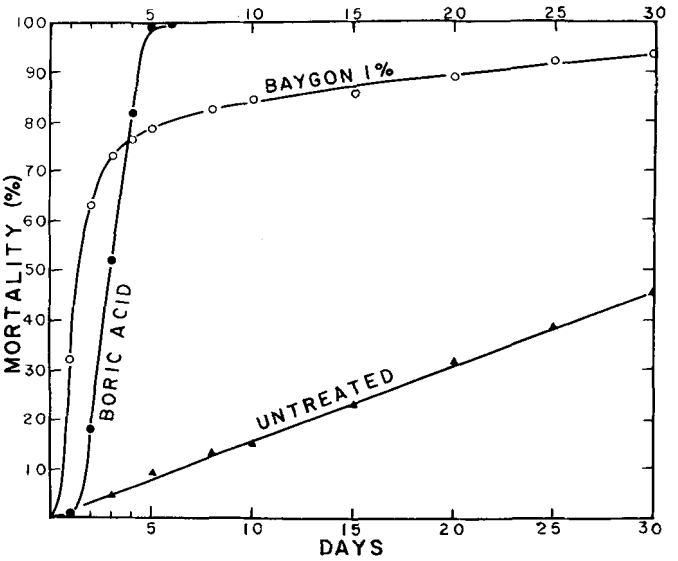


TIME-MORTALITY CURVES FOR GERMAN COCKROACHES IN TREATED CHOICE BOXES, SHOWING CHARACTERISTIC CURVE FOR AN INSECTICIDE OF LOW TOXICITY, BUT RELATIVELY NONREPELLENT (BORIC ACID) AND ONE OF HIGH TOXICITY, BUT HIGHLY REPELLENT (BAYGON)

(average of 16) shocks to learn to avoid the electrified dark area of their "learning box" and to remain in the light, when the criterion for learning was nine avoidances in 10 trials. No significant difference in learning ability was found between sexes. Wide variation in the learning ability of individuals of the same species and sex has been noted by all investigators. An average of 28.8 shocks was required, after forced activity of the insects on a treadmill for 10 minutes previous to the test. When a 50-minute period of rest followed the 10 minutes of activity, an average of 21.9 shocks was required. Excessive irritability resulting from forced activity was considered to be the principal factor retarding the learning process.

Relearning

A study of the ability of adult American cockroaches to relearn darkness-avoidance after intervals ranging from one to 24 hours following the initial learning showed that when half of the cockroaches were placed in a dark square box after the training trials, they tended to remain inactive in the corners of the box until removed for the relearning trials. The control insects placed in a dark round box continued to crawl about because there were none of the usual intersections and corners into which cockroaches normally congregate to rest.

Relearning was accomplished more rapidly than the original learning. Among the control insects (those which were active after the learning trials) the number of electric shocks required for relearning varied from 41.8 to 73.8 per cent of those required for learning. The percentages increased with the increasing intervals between the learning and relearning trials, which ranged from one to 24 hours. When the insects were kept in a dark square box in which they remained inactive after the learning trials, the corresponding percentages varied from 16.6 to 26.2.

Effects of rest

Although rest did not significantly improve learning ability, it greatly improved the ability to relearn. It was concluded in the studies with electric shock that postlearning inactivity of the cockroaches may be compared with the state of natural sleep in its favorable effect upon retention and relearning demonstrated in experiments with humans. Other investigators also found that inactivity enforced by cold or anaesthetics did not have a favorable effect—in fact retention was decreased.

Also observed was the cockroach's initial incautious rush into the electrified dark compartment of the learning box, usually during the first five to 10 trials, and its subsequent approaches with antennae actively exploring the floor and walls. Its front legs are used to test the grid, and upon receiving a light shock, it steps back. It eventually approaches the dark compartment slowly, then turns back slowly without entering. Once the cockroach learns to avoid darkness it makes few mistakes in later trials.

Barriers of dust

The same sequence of events is followed when the German cockroach is confronted with a barrier of insecticides or desiccant dust. For example, when 1 cc of insecticide dust was placed in each of the four corners of a box in subdued light, the cockroach would invariably make at least some contact with it—some individuals crawling over it. However, subsequent contacts were made with greater caution; they usually involved only a tentative probe with the insect's front legs or antennae. A cockroach, if not paralyzed during its initial contacts, may learn to avoid the piles of dust completely. With organophosphorous or pyrethroid insecticides, recovery from brief encounters with dusts was frequent and the recovered insects often lived as long as those in untreated controls. Individuals most cautious in their initial contacts seldom picked up a toxic dose of insecticide.

The ability of cockroaches to learn to avoid deposits of residual insecticides or

inert dusts was best demonstrated and evaluated by the use of "choice boxes," as shown in the photo. The boxes, 1 ft square and 4 inches high, were made of ½-inch pine drawer siding with a fiberboard floor and a partition in the middle dividing the box into two equal compartments. A ½-inch hole at the top of the partition wall allowed cockroaches to crawl from one compartment of the box to the other. It was important to drill the hole at the very top of the partition wall because cockroaches normally crawl along the intersections and therefore cannot fail to find the hole.

Choice box

The light half of the box was screened on each of three side windows, covering a total area of 53 square inches. Both halves were covered with plexiglass, but the dark half was also covered with fiberboard. Generally 20 adult male cockroaches were placed in the light half of each of five choice boxes. As many as 80 boxes have been used simultaneously in one experiment. Food and water were placed in the light half of the choice box.

Most of the time cockroaches occupied the dark half of the choice box, but if the entire compartment surface was treated with any kind of insecticide formulation or inert dust, some of the insects, after a few contacts with the deposit, nearly always learned to stay and live in the light half. The toxicity or other hazard of foreign substances placed in the dark half of a choice box was similar to the punishment from the electrified grid used by previous investigators. Cockroaches appeared to become aware of the potential hazard of these substances at the first contact and then initiated evasive behavior.

In choice boxes and in field trials the long-term efficacy of an insecticide against German cockroaches has been approximately inversely proportional to the immediate hazard (toxicity, desiccating action, etc.) that it presents to the insects. The more volatile insecticide was not necessarily the more repellent. For example Baygon (v.p. 3×10^{-6} mm Hg at 20°C) was both more toxic to cockroaches and more repellent than diazinon (v.p. 1.4×10^{-4} mm Hg at 20°C). Silica aerogel (nonvolatile) was more repellent than Baygon. The least repellent insecticide tested was boric acid. Even though it was the least toxic of all insecticides tested, 100 per cent cockroach mortality was reached more rapidly in choice boxes with boric acid than with other insecticides.

When only a part of the dark compartment, such as the floor, was treated with insecticide, the cockroaches could remain on untreated surfaces without having to leave the dark half. This improved the ability of the insects to avoid deposits of the more repellent insecticides and further reduced their relative efficacy.

A typical example of the results with boric acid compared with the results of other insecticides, is shown in the graph. Ten cubic centimeters of screened boric acid was deposited evenly on the floor of the dark half of each of five choice boxes and 3 ml of 1 per cent Baygon emulsion in five others. Forty adult male German cockroaches, *Blattella germanica*, were placed in the light halves of the boxes. The rate of mortality was initially much greater with Baygon than with boric acid, but in four days the mortality was higher in the boxes treated with boric acid and in six days it had reached 100 per cent. In the choice boxes treated with Baygon there were still 6 per cent of the insects alive 30 days after treatment.

Relationship

Choice boxes may be used to show a similar relationship between boric acid and the other currently used organic insecticides, sodium fluoride, and dust desiccants, and when using other species of domiciliary cockroaches: the oriental (*Blatta orientalis*), American (*Periplaneta americana*), and brown banded (*Supella supellectilium*). One exception was found in trials with Baygon used against the oriental cockroach. This relatively sluggish species apparently could not withdraw from Baygon deposits rapidly enough to avoid 100 per cent mortality within a few hours—not because Baygon is particularly toxic to oriental cockroaches; in fact it required 48 minutes of continuous contact to obtain a 50 per cent kill of oriental cockroaches, compared with only 17 minutes for German cockroaches, when the two species were continuously confined with the same dosage of Baygon residue.

Most of the field experiments were made in large apartment buildings in which a number of insecticides could be compared in apartments of similar construction. The type of construction, furnishings, amount of clutter, etc. have an influence on the efficacy of an insecticide. The more "complex" the environment, the greater are the opportunities for cockroaches to escape from insecticide deposits and find refuge in untreated areas.

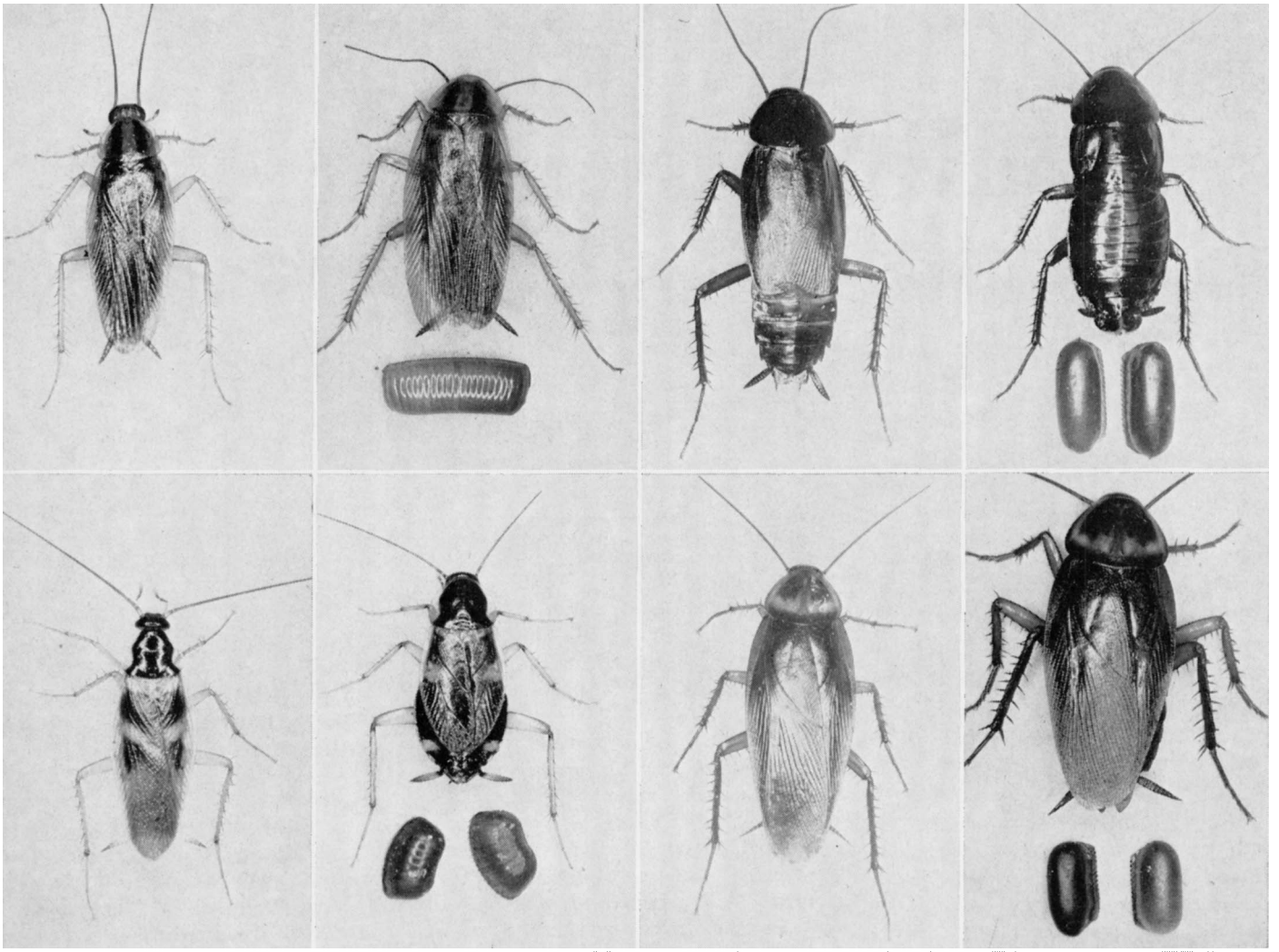
One or two traps were placed in each apartment, usually behind or at the side of the refrigerator or stove or under the sink, each of which is frequently an area of maximum infestation. A trap consisted of a quart jar in which a teaspoonful of sorptive clay was shaken to make the inner surface dusty. A half slice of bread was placed in each jar. Cockroaches were attracted to the bread, but could not escape from the jars because of the slippery inner walls. The relative cockroach populations were determined before treatment and usually one, three, and six months later.

Boric acid

The table shows the relative efficacy of boric acid in apartments with "simple" and "complex" environments. The simple apartments were heavily infested, but were small, new bachelor apartments of "tight" construction that prevented the access of cockroaches to wall and subcabinet voids. They had meager furnishings and a minimum of clutter. The apartments of complex environment were of "loose" construction, allowing easy access of cockroaches to wall and subcabinet voids and containing many cracks and crevices. The complex apartments were also overcrowded, and usually contained large families and excessive furnishings and clutter.

It was found that repellent insecticides were at the greatest disadvantage in this type of apartment because they were easily avoided by cockroaches when there were many suitable untreated areas of refuge. As may be expected, it was this type of apartment in which the repellent organic insecticides (Baygon, diazinon, and dichlorvos) performed less effectively, as shown in the table. Although in the apartments with simple environment the results with Baygon and diazinon-dichlorvos appeared to be reasonably good three months after treatment, in six months the tenants began to complain of reappearing infestations and these apartments were all retreated with boric acid.

The apartments with the simple environment happened to have fairly large numbers of oriental cockroaches. In the 20 apartments where boric acid was applied, 213 were trapped before treatment and none after. In the 10 apartments where diazinon-dichlorvos was applied, 119 were trapped before treatment and the number trapped one and three months after treatment amounted to 6.7 per cent and 9.2 per cent, respectively, of the original population. On the other hand, in subsequent field experiments, Baygon 0.5 and 1.0 per cent emulsion gave consistently excellent results.



The four common species of cockroaches infesting homes and other buildings (males left, females and egg cases right). top left, German (Blattella germanica); **top right, oriental** (Blatta orientalis); **lower left, brown-banded** (Supella supellectilium); **lower right, American** (Periplaneta americana).

The apartments with complex environment were in the housing projects of the San Francisco Housing Authority. In January 1966, boric acid powder was applied thoroughly under and behind refrigerators, stoves, sinks and cabinets, in shelf intersections and corners, in cracks and crevices, in voids under cabinets, and in all out-of-the-way places likely to be infested. Baygon 1 per cent emulsion was applied in certain areas of the kitchen and bathroom, such as under the bathroom sink. An average of ¼ pint per apartment was used. During the following two years, 6000 apartments were treated twice with an average of 1 lb of screened technical boric acid per apartment used in each treatment. The only apartments in which this infrequent treatment was less than satisfactory were those which were vacated. In vacated apartments, the refrigerator and stove were removed, cleaned, and replaced after the floors were mopped and the shelves, pantries, cabinets, and closets were painted. Ordinarily these procedures would be expected to decrease the cockroach population, but by removing the boric acid the infestation was eventually increased.

Boric acid has also been used successfully in larger houses, restaurants, cafeterias, markets, drugstores, rest homes, and hospitals. Some pest control operators are using boric acid for cockroach control—either the dust alone, dust supplemented with currently popular sprays in those areas in which dusts are not appropriate, or following a pyrethrum aerosol applied in the kitchens or other areas in which the infestation may be especially severe. These pest control operators have reported a great improvement in control over previously used conventional liquid sprays.

Boric acid, stabilized to prevent lumping, is being sold in 1-pound cans throughout the United States in leading department stores and in some hardware stores.

The characteristics of boric acid that are of special merit include its minimal repellency to cockroaches and the fact that it is inorganic and therefore effective as long as it is allowed to remain in place after it is applied. It should be reapplied wherever it is removed, accidentally or otherwise, or where it becomes wet, after which the deposits are not as readily picked up by the insects. It is relatively safe to humans, and does not give rise to vapors as do the organic insecticides, but it should be kept out of reach of small children, who may eat substantial amounts of almost any powder.

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