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Beyond origami: using behavioural observations as a strategy to improve trap design

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Abstract

In contrast to *ad hoc* methods of developing traps for pest monitoring systems, a systematic approach using direct observation of animals allowed a greater understanding of the reasons why trap catch was significantly different in traps of basically similar design. The information gained using this approach could then be used to guide the further development of the trap. The same feature on two related designs of cockroach trap was varied: the slope of the ramp leading into the trap was either 60°, 30°, or 0°. The 30° ramp version of both traps caught significantly more *Blattella germanica* (L.) (Dictyoptera: Blattellidae). The 60° and 0° ramp versions both caught equal, lower, numbers but observation showed that these net catches were achieved by quite different means; few insects entered over the 60° ramps but none escaped, whereas all entered over the 0° ramps but half escaped. Similar approaches could be applied to other insect-trap systems.

Introduction

Traps are widely used to monitor insect pest populations for integrated pest management and field testing of pheromone blends. Despite the vital importance of trap design in developing trapping systems (Cardé & Elkinton, 1984), the design and testing of a trap is rarely given the attention devoted to the pheromones or other attractants which will be used in it. Applied origami, a non-systematic approach to the assessment of different designs, appears to have been a common procedure, with traps designed more as an act of faith than by experiment. Despite the large influence it can have on the size of catch, trap design is rarely investigated in detail. Lewis & Macaulay (1976) cite differences of up to 30 fold in the catch of the same species, with the same dose of sex attractant, but different trap design. Both they and Vale (1982a, b) advocate a more systematic approach. In this paper we show that relatively small changes in the design of traps can greatly improve their efficiency, and that the differences can be explained by observation of the behaviour of individual insects as they contact and enter the trap.

The usual approach is to test a variety of very different trap types regardless of the possibility that differences of equal magnitude might be found by relatively minor changes to any one of the traps compared. Such uncritical comparisons do not provide an understanding of how the traps work and how they could be improved. In contrast, the experiments described here on one trap feature allow prediction of features that will increase the efficiency of other traps.

Traps of various kinds have been used widely in cockroach detection and population sampling (eg. Barak *et al.*, 1977; Owens & Benett, 1983; Moore & Granovsky, 1983; Ballard & Gold, 1984; Rivault, 1989; Schal & Hamilton, 1990). Here we describe work on the behaviour of the German cockroach, *Blattella germanica*, but the techniques could be applied to any insect-trap system.

Materials and methods

Experimental insects. The *B. germanica* were reared in 32 litre plastic bins with rolls of corrugated cardboard as harborages and rat-cake (Rat and Mouse No. 1 (Modified) Special Diet Services, Wm. Lillico & Son Ltd) and water *ad libitum*. The insectary was kept at 27 °C with a reverse day/night cycle (14L:10D), lights off at 10:00 h. A mixed population of adults and late instar nymphs was used for the experiments.

Test arenas. The arenas were $60 \times 85 \times 10$ cm melamine surfaced wood with a removable glass lid. The walls were coated with polytetrafluoroethylene (PTFE) to prevent the cockroaches climbing them. After each experiment the arenas were thoroughly cleaned with alcohol. Fresh unused traps, lures and harborages were used for all the experiments.

The experiments were run at room temperature (20 °C) and started 4 h after lights out, in the most active period (Fuchs, 1983; Dreisig & Nielson, 1971). In each experiment newly made harbourages in the form of four $140 \text{ mm} \times 50$ mm diameter rolls of corrugated cardboard were provided so the insects would not be entering the traps for shelter. The cockroaches were placed in the arena 5 min before the experiment was started by the addition of the test trap or traps.

Food lures. The proprietry food based lures were supplied by AgriSense-BCS, Treforest UK. Identical lures were used throughout the experiments. The only variable was the trap design. Preliminary experiments (below) showed far more cockroaches were caught in the baited trap, when traps with and without baits were placed in the same arena, although similar numbers of cockroaches came into contact with each trap.

Preliminary experiment

Two traps, one baited and the other not, were placed in the centre of the arena. The arena contained 4 harbourages in the corners, a source of drinking water, and was lit by a white 60W fluorescent tube on the same LD cycle as the insectary (above). The positions of the traps in relation to the water and the orientation of the arena were alternated over the series of experiments. Five minutes before the start of the experiment 20–35 insects were placed in the arena. The numbers caught in the two traps after 24 h were recorded.

At the end of the experiment, after 24 h, almost all the cockroaches caught were in the baited trap in each pair (chi-square on the summed data 42.1, df = 1, $P < 0.001$, and the replicates behaved the same: heterogeneity chi-square 1.3, df = 3, $P > 0.1$). The percentage of the total caught by the baited trap was between 80 and 100%.

Behavioural experiments.

1) During a 2 h period the behaviour of any cockroach when it came into contact with the trap was observed. Twenty five insects were in the arena together with one baited trap. During the experiment the arena was under the light of a white 60W fluorescent tube. The following were recorded: the point of first contact with the trap (end or the long side); behaviour after initial contact:

a] walk off the trap before reaching an opening (*on and then leave*);

b] reach the 'ramp' of an opening into trap and then leave (*Reach ramp and then leave*);

c] walk into the trap without pausing at the opening (*Go straight in*);

d] walk into the trap with a pause at the opening (*Pause, go in*).

At the end of the experiment the net catch was recorded and from this the number of escapes calculated.

The behaviour of the cockroaches in response to two sticky trap types (Fig. 1) was evaluated with the slope of the ramps leading into the trap at 60°, 30°, or 0° (ramps stuck down onto the glue inside). The design of the two traps differed only in the outer cardboard shape and the shape of the openings. The Tent-Trap was a delta shaped sticky trap. The Flat-top trap was similar but had a lower, flat roof. The outside surface of the Tent-Trap was yellow green, that of the Flat-top trap was white. Three replicates were made for each trap/ramp angle combination. In the same series of experiments the Tent-Trap was also tested with the ramps cut away.

2) The most effective ramp angle for each trap design, 30°, was tested in an additional paired trap experiment in which the catches at the end of a 24 h period were compared. The experimental conditions were the same as those for the preliminary experiment, except that both traps were baited.

Statistical analysis. Data expressed as proportions were arcsine transformed before statistical analysis to reduce the dependence of the variance on the mean (Sokal & Rohlf, 1981, p 427).

Results

1) Trap type and ramp angle. Relatively minor changes in the trap design (Fig. 1) caused major changes in trap efficiency (Fig. 2). For example, the catch was increased by more than 50% if the angle of the opening slopes to the trap was reduced from 60° to 30° in both types of trap. However, trap catch fell if the slope was further reduced to 0°. The observations of the behaviour of the individual cockroach approaches explained these results.

The analyses allow a separation of the effects of trap type (Tent- and Flat-top) and ramp angle (60, 30, 0°), described in detail in Figure 3. The number of visits to the traps in a 2 h observation period was very similar irrespective of the trap type or ramp angle (overall mean $\pm$ 1 s.e.: 17.3 ± 0.25, $n = 21$; range 15–19) (Fig. 3a) but these differences were nonetheless significant. The difference between the trap types was perhaps due to the different trap profiles but the differences between ramp angle were surprising although they could possibly be explained by an improved airflow over the lure in the traps with shallower ramp angles. However, to remove the number of contacts as a factor, the observations of behaviour after contact have been expressed as a proportion of the number touching the trap. Calculations of the proportions of insects meeting the sides and ends support this treatment of the data (see below).

Between 18 and 38 percent of insects walked onto the trap and then left without encountering an opening (Figs. 2, 3b). This was significantly affected by the trap type but not by the ramp angle (Fig. 3b).

However, the behaviour of the insect on finding an opening to the trap was independent of trap type but greatly affected by the slope of the opening ramp (Figs. 2, 3c-e). All the insects hesitated on reaching the edge of a steep ramp (60°); instead of entering directly they would walk along the edge and between one third (Flat-top trap) and more than half (Tent-Trap) turned back from the trap and left. If the ramp slope was reduced to 30°, the majority of cockroaches still hesitated but a higher proportion entered. If the slope was reduced to 0°, more than half went in without pausing and none turned back on reaching the opening (Fig. 2).

The data for insect entry would suggest that the best trap would have either no entry ramps or have 0° ramps. However, the net catch was greatest in the trap with the ramp slopes at 30° (Figs. 2, 3f) because although traps with 0° or no ramp provided no obstacle to entry and more

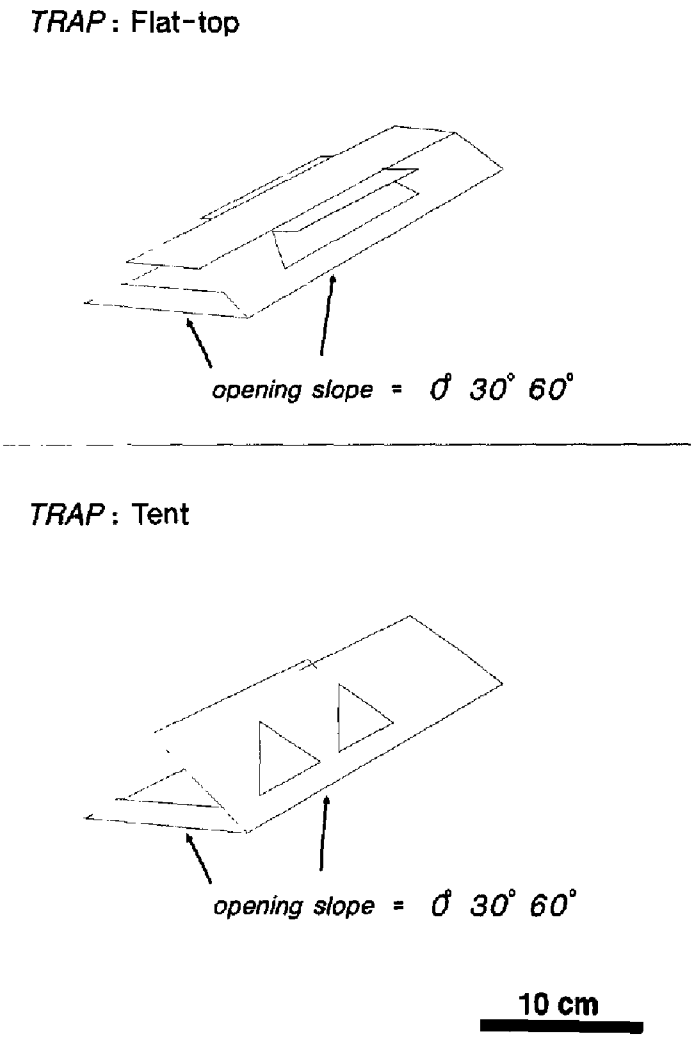

Fig. 1. The two types of sticky trap. The angle of the opening slopes to the traps were 60°, 30° or 0°. The Tent-Trap was also tested with the opening slopes cut away altogether, equivalent to 0° slope.

entered, the cockroaches could also escape more easily (Figs. 2, 3e). The ramp provided an overhang which both helped ensure that cockroaches climbing into the trap were totally caught on the glue, and made escape more difficult. Without a ramp the insects only got their forelegs caught and were observed pulling themselves free using their remaining unstuck legs.

The use of data pooled for the side and end ramps was justified, and further confidence in the design of the experiments given, by analysis of these categories. The ratio of total numbers first contacting the sides and ends of each of the traps could be explained by the ratio of their lengths (using the ratio of their lengths to predict the expected encounter rate (2.01:1, side:end). Heterogeneity Chi-square = 5.8, df = 5, $P > 0.1$, deviation from predicted ratio chi-square = 1.7, df = 1, $P > 0.1$, NS). In a similar way the numbers entering the side and end openings could be explained by the ratio of the opening lengths: (1.13:1, side:end, heterogeneity chi-square = 2.8, df = 5, $P > 0.1$, deviation from predicted ratio chi-square = 0.06, df = 1, $P > 0.1$, NS). The low het-

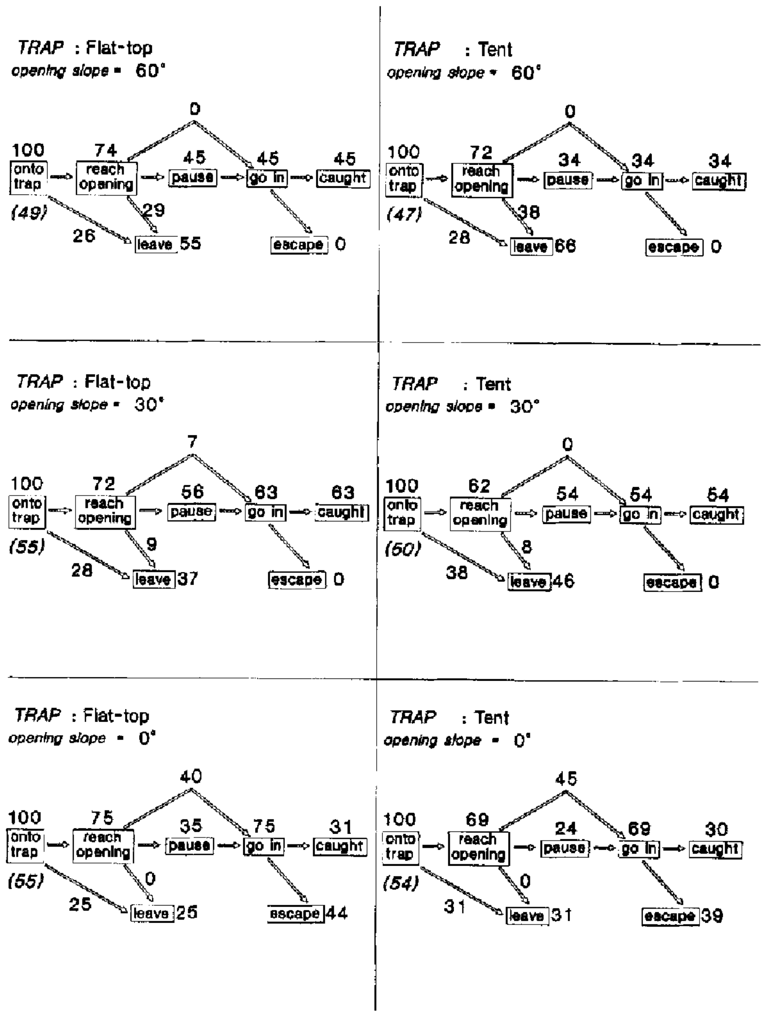

Fig. 2. The behaviour of *B. germanica* after contact with the trap. The solid numbers are the proportion as a percentage of the number contacting the trap (italic). The numbers are summed for 3 replicates in each case.

erogeneity chi-square confirms that the ramp angle had the same effect whether at the side or end of the traps.

Cockroaches treated the Tent-trap with ramps cut away in the same way as they did the 0° Tent-trap. More reached the opening but the proportions following the different paths in the ethogram downstream of this were within 0.01 or 0.02 of the same proportions in the 0° Tent-trap.

2) Overnight comparison of 30° version of each trap. The flat-top trap (30°) gave significantly higher catches than the Tent-Trap(30°) in 8 paired tests (Heterogeneity Chi-square = 1.04, df = 7, $P > 0.9$, deviation from predicted equal catch chi-square = 15.35, df = 1, $P < 0.001$ (summed catches: 65 in Tent-traps, 118 in Flat-top traps). The result is in the direction predicted by the total catches in the more detailed experiments (Figs. 2, 3) but the observations in those experiments showed that the net catch per cockroach contact of the trap showed no difference between the 2 trap types. It is possible that the 24 h experiments results may be explained by other effects such as differences in the proportion escaping over a longer time period or more subtle differences in encounter rate.

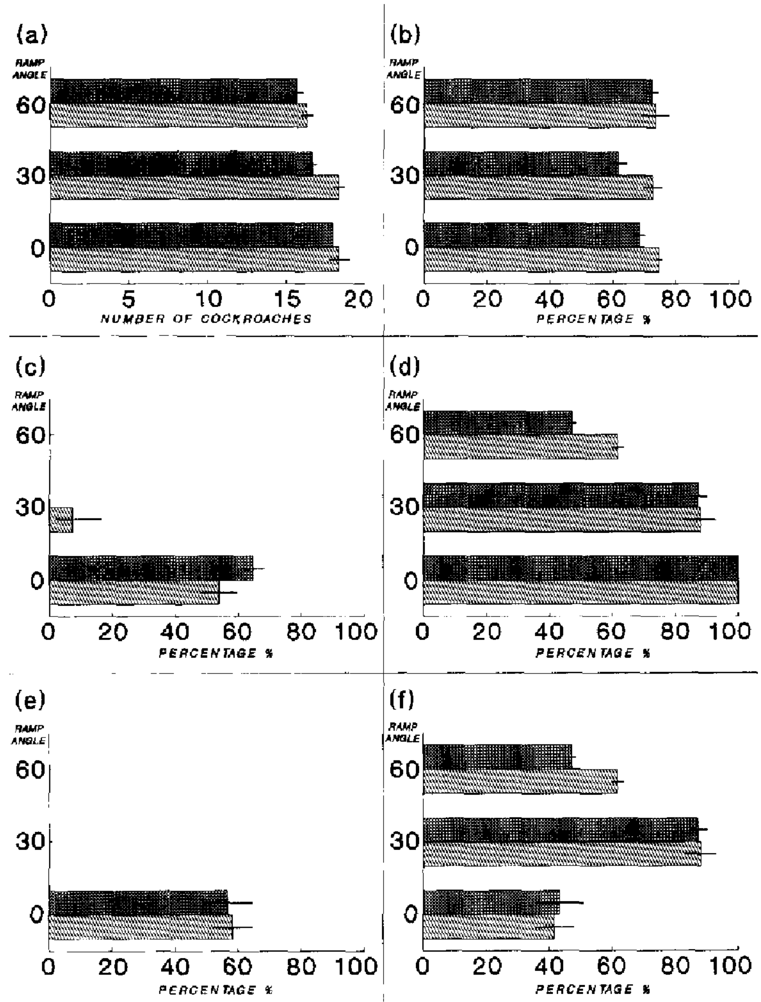

Fig. 3. Analyses of the trap associated behaviour of *B. germanica*. Two way ANOVA on arcsin transformed data, untransformed after analysis (Means ± 1 s.e.). There are two factors in each analysis: **Trap** (2 levels: Tent- and Flat-top) and **Ramp angle** (3 levels: 60, 30, 0°). a) number of *B. germanica* contacting the trap in 2 h experiment: Trap $F = 8.0$, $df = 1$, $P < 0.05$; Ramp angle $F = 16.6$, $df = 2$, $P < 0.001$. b) number reaching opening ramp as percentage of number contacting trap: Trap $F = 7.1$, $P < 0.05$; Ramp angle $F = 2.1$, $P > 0.1$. c) entrances without a pause as percentage of total number entering: Trap $F = 0.07$, $P > 0.5$; Ramp angle $F = 74.4$, $P < 0.0001$. d) entrances as percentage of number reaching opening ramp: Trap $F = 3.1$, $P > 0.1$; Ramp angle $F = 206.9$, $P < 0.0001$. e) escapes as percentage of number entering trap: Trap $F = 0.001$, $P > 0.9$; Ramp angle $F = 340.4$, $P < 0.0001$. f) catches as percentage of number contacting trap: Trap $F = 1.1$, $P > 0.1$; Ramp angle $F = 47.2$, $P < 0.0001$.

Tent trap   Flat-top trap

Discussion

The behaviour of insects approaching and entering, or not entering, a trap is more complex than the often *ad hoc* approach to trap design acknowledges. Such *ad hoc* studies tend to rank a range of widely different traps without providing any understanding of why the traps catch differently. While such studies may be an essential first step, they rarely provide a basis for deciding important features for development because the traps differ in so many different ways.

Vale (1982b) advocates a fusion of analytical and empirical approaches. A more systematic approach, in particular one in which the behaviour of the insects is observed, allows an analysis of individual trap features and prediction of the ways that the trap could be further improved. The use of two related trap designs altered in the same way, allowed us to identify both the effect of the major factor, ramp angle, and differences between the traps. ANOVA was a particularly effective way of analysis for this type of experiment.

These experiments also show the importance of observing the insects rather than relying on the catch at the end of the experiment. The net catches at the end of the experiment did not reveal the way that entry of the animals and their escape were both being affected by the change in ramp angle, and that the net catch was a balance between these. Without watching the insects, these effects would not have been exposed. Vale (1982a, b) and co-workers have demonstrated elegant ways of approaching this problem indirectly to give information on the detailed breakdown of numbers of tsetse flies approaching and going into traps.

Traps used for insect control, such as those for tsetse flies, require the most efficient design possible, that is, one that has the highest chance of trapping any target insect that approaches. Similiar considerations apply to traps for insects in public health or food storage where the maximum sensitivity is needed as the threshold for insects may be low or even zero. By contrast, for crop or forest pests there may even be an advantage in a less sensitive trap which nonetheless catches a constant proportion of the males (Cardé & Elkinton, 1984). The experiments reported here show that the use of a systematic approach and making small alterations to existing, moderately effective trap designs, can greatly increase trap efficiency. Even comparatively small changes can be important. An experimental approach also showed the importance of design details for stored product beetle traps (Wyatt *et al.*, 1989). We are not aware of similar small scale systematic changes in traps designed for flying insects.

However, not everything about the trap oriented behaviour is explained. The experiments would have been improved by observation in the field although this may be less important for a domicilliary animal like the cockroach. In particular we do not know about the encounter rate and this should have been investigated. For example it would have been useful to know the proportion of those approaching within, eg 10 cm, which encountered the trap (equivalent to Vale's **a** value (Vale, 1982a)). In this study we did not distinguish the behaviour of nymphs, adult females and males. The conclusions of the experiments do not depend on this but it would be interesting to investigate potential differences between the trap behaviour of these groups.

More specifically, the experiments allow some generalizations about some of the features of improved traps. For the general design of traps tested, the flaps and ramp are necessary to prevent escape from the trap but these ramps, particularly if they are steep, tend to discourage the cockroaches from entering. Therefore, a balance has to be sought between a ramp steep enough to prevent escape but not discourage a significant number of cockroaches from entering. An adhesive better able to retain the insects in the trap would allow the ramps to be safely removed and the catch improved as entry would be increased. The observation that many insects left the trap without reaching an opening ramp suggests that, as the number of cockroaches entering was proportional to the size of the openings, greater catches would be obtained if the openings were enlarged.

While these conclusions are perhaps specific for this insect-trap system, we feel that the general approach could be very usefully extended to other insect-trap systems.

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