more than 5 km apart, only one (A × C) did not. Significantly, even these anomalous cases suggested the occurrence of neighbor recognition in that polarized preexisting social relationships were nonetheless apparent for the "neighbor" pair (L × M) which did fight and were absent for the single "stranger" pair (A × C) which did not. Neighbor pairs engaged in significantly less fighting per hour than did strangers (median test, Fisher exact probability, $P < .05$).

The results obtained for red foxes (Table 2), although differing in behavioral detail, conform to the general "neighbor-stranger" dichotomy reported above for raccoons. Thus, of five neighbor pairings (arbitrarily defined here as foxes trapped less than 8 km apart), distinct dominance-subordinance polarity was apparent prior to any further interactions in four cases—the fifth (G × E) was indeterminate since one animal exhibited dominance postures while the other did not indicate subordinance. (It may be significant that these animals were trapped 7.5 km apart, a possible intermediate distance between neighbors and strangers.) The dominance-subordinance relationships observed among the foxes involved the basic postural components already described for that species (*5*). Thus, the dominant animal demonstrated a characteristic "threat gape" with mouth partially opened and vertical wrinkling of the muzzle, producing a snarl; ears lateral and forward and the head held higher than the subordinate whose mouth was more widely opened with horizontal retraction of the lips ("grin"), smooth muzzle, lateral and downward compression of the ears, and head lowered with neck extended.

Of the six stranger pairings (animals trapped more than 8 km apart), dominance-subordinance polarity was immediately apparent in only one case (C × F). Neighbor pairs thus demonstrated a significantly higher frequency of initial dominance-subordinance relationships than did strangers (Fisher exact probability, $P < .05$). Five of the six stranger pairings (all of those in which no prior polarity was apparent) resulted in a characteristic "upright display"—of the neighbor pairings, only one (E × F) produced an upright display, and that was the briefest of all observed (3 seconds). During the upright display, forepaws were placed on each other's shoulders with neck hairs erected. Both participants generally screamed loudly, with their mouths wide open and less than 8 cm apart. In three of these cases (A × C, B × C, and D × E) this display was followed by a horizontal posture in which the participants lay down about 1 m apart, still screaming, with the jaws still open but less wide, ears flattened and compressed laterally, and the tail wound around the animal's side, with the tip pointing toward the other animal. Stranger pairs engaged in significantly more upright displays of longer duration than did neighbors (Fisher exact probability, $P < .05$). In two cases, upright displaying was followed by a brief fight with growls and apparent attempts to bite the opponent. Both of these fights involved strangers.

The testing conditions employed in this study were grossly unnatural and therefore the specific data reported here should probably not be treated with particular reverence. On the other hand, I believe that the general pattern reflects the real world of free-living animals from both species: for both raccoons and red foxes, neighbors showed a consistently greater frequency of initial social polarity than did more distantly trapped animals, thus suggesting some preexisting social relationships. A higher level of interactive intensity (growling in raccoons, upright displaying in red foxes) was particularly characteristic of animals trapped at greater distances, and actual fighting—the highest level—was limited almost exclusively to these animals.

In a previous study (*6*) it was suggested that a rudimentary form of social organization occurs among feral house cats; this is the first documentation of such a system among free-living, native species. The neighbor recognition described here may be achieved and maintained in a variety of ways among the free-living animals. Further research should help identify them.

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Olfactory Learning-Set Formation in Rats

Abstract. *Rats trained on 16 two-odor discrimination problems showed rapid acquisition of a learning set and one-trial learning by the end of the problem series. Learning to sample odor cues before responding and adoption of a "win-stay, lose-shift" strategy probably accounts for the virtually errorless learning. Learning-set performance of rats trained with odor stimuli is comparable to that reported for primates trained on visual cues.*

Learning to learn (learning set) occurs when training on a series of discriminations of the same general class results in progressive improvement in solving each subsequent problem. Although improvement over a series of nonspatial, multiple-stimulus problems culminating in one-trial learning is usually observed only for primates, the level of asymptotic performance in learning-set tasks has been widely used by comparative psychologists to rank species for intelligence or behavior plasticity (*1, 2*). Theories attempting to relate level of intelligence with phylogenetic status on the basis of learning-set performance have been criticized because they fail to take into account species differences in sensory capacities, including "preparedness" to form specific stimulus-response associations (*1–5*). When rats, for example, are given both olfactory and visual or olfactory and auditory cues, they preferentially attend to the odors and learn little or nothing about the visual or auditory cues (*6*). Experiments in which an olfactometer was used for precise control of odor stimuli demonstrated that rats trained with odors may show very rapid acquisition of simple discriminations and significantly faster learning of reversal sets than animals trained with visual or auditory cues (*6*). In the present experiment, we examined the ability of rats to form a learning set when given a series of two-odor discrimination problems.

Subjects were trained in a modified glass funnel fitted with a response key and a water delivery mechanism. The wide end of the chamber was connected to an exhaust and the narrow end to an odorizing system (Fig. 1). A stream of air (4 liter/min) filtered through silica gel and activated charcoal (Fig. 1, main

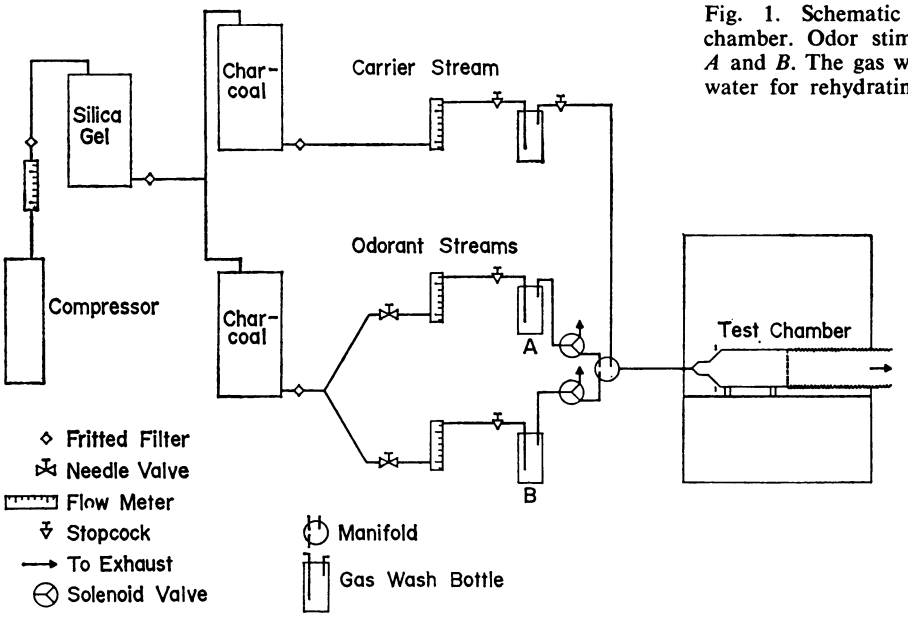


Fig. 1. Schematic representation of olfactometer and test chamber. Odor stimuli were generated in gas washing bottles *A* and *B*. The gas washing bottle in the carrier stream contained water for rehydrating the air.

air stream) passed continuously through the chamber. Two independent odor streams (0.125 liter/min) were controlled by electrically operated Teflon valves. Energizing a valve added an odor into the main air stream.

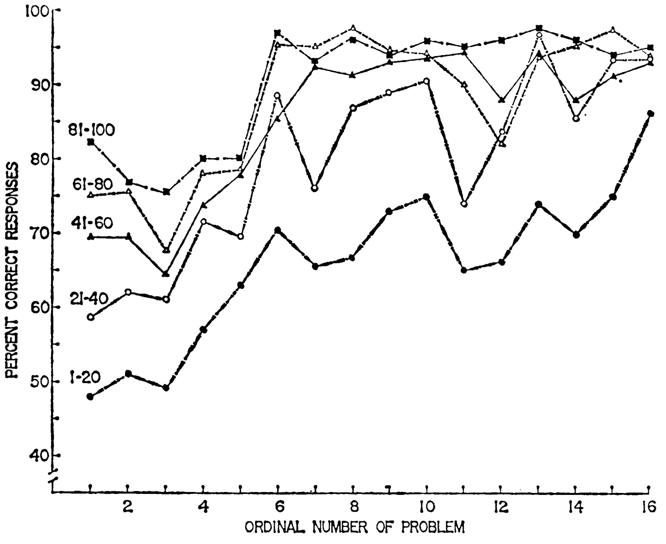
A discrete-trials, "go, no-go" successive discrimination training procedure was employed. A trial consisted of presenting either the positive (S+) or negative (S−) stimulus for a maximum of 5 seconds. A key response in the presence of the positive stimulus resulted in termination of the trial and delivery of a 0.04-ml water reward. Key responses in the presence of the negative stimulus terminated the trial but were not reinforced (*7*).

Because multiple-problem learning-set studies require a different and independent pair of stimuli for each successive problem, selection of odor pairs presented an impotrant methodological problem in the present study. To eliminate potential stimulus generalization effects across members of different stimulus pairs, a series of floral perfumes were used as stimuli. The stimuli for each problem consisted of two slightly different varieties of a single floral odor (such as rose) diluted to a 0.1 or 1.0 percent solution with 70 percent ethanol (*8*).

In experiment 1, eight rats were first trained to make a brightness discrimination to ensure familiarity with the operant procedures and reinforcement contingencies. The animals were then trained for 100 trials on each of 16 odor discrimination problems. Four rats were trained with the 0.1 percent solutions (group 1A) and four with the 1.0 percent solutions (group 1B).

In a second experiment with four rats, similar procedures were used except that animals were trained to criterion on each problem and training conditions were altered slightly in an effort to optimize discrimination learning (*9*).

After each odor problem, the valves and ductwork of the odorizing system were washed thoroughly with absolute ethanol, rinsed with hot tap water, and air-dried. After termination of the test series, two animals from each group were given control tests either with air flow through both odor channels turned off or with identical stimuli in both odor channels to ensure that only odor cues were available as discriminative stimuli during the learning-set series (*10*). Most of the animals were observed continuously during training.



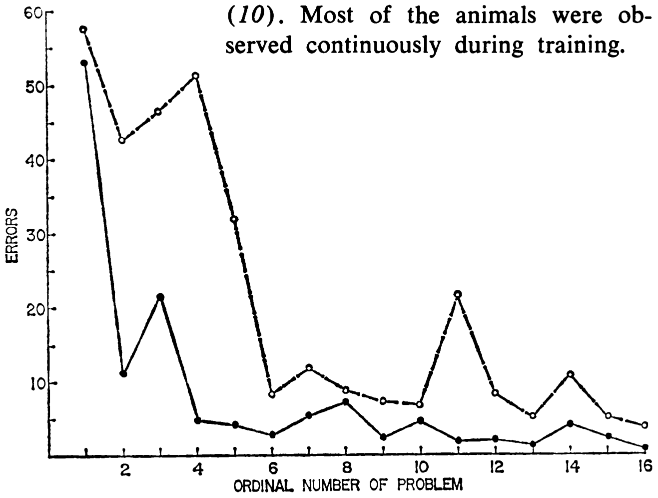


Fig. 2 (left). Mean percentage of correct responses for the eight rats in experiment 1 as a function of ordinal number of problem. Results are given for successive 20-trial blocks within problems. Improvement in performance within each problem is given by points plotted above the ordinal number of that problem. Improvement in performance across problems for each trial block is shown by the individual curves. For the first few problems, improvement is gradual and asymptotic performance is only about 80 percent correct responses by the last trial block. By the last problem, acquisition is rapid and most of the learning occurs within the first 20 trials. Fig. 3 (right). Mean number of errors to performance criterion as a function of ordinal number of problem for the eight rats in experiment 1 (dashed line) and the four rats in experiment 2 (solid line). Rats in experiment 1 were trained to discriminate qualitatively similar odors (difficult discrimination); the rats in experiment 2 were trained to discriminate qualitatively different odors (easy discrimination). Both groups show a rapid improvement in performance over the first six problems. Rats in experiment 2 showed nearly errorless acquisition of each problem in the later half of the problem series. Criterion performance was 95 percent correct responses in a block of 20 trials.

Each of the 12 rats showed acquisition of an odor learning set. In Fig. 2, the mean percentage of correct responses in 20-trial blocks for each of the 16 problems is shown for the eight rats trained for 100 trials on each problem (experiment 1). Performance improved rapidly both within problems and across the problem series.

The mean number of errors made in reaching the 95 percent performance criterion on each problem for experiments 1 and 2 is shown in Fig. 3. Rats trained with the qualitatively similar odors (experiment 1) showed a gradual reduction in errors to an asymptotic level of approximately five errors per problem. Group 1B (1 percent odor dilution) made significantly fewer errors than group 1A (0.1 percent odor dilution) on problems 1 to 8 (150.8 compared to 322.8, $P < .05$) and on problems 9 to 16 (36.3 compared to 102.5, $P < .05$). The four rats trained with qualitatively different odors (experiment 2) showed a sudden improvement in performance on the second problem and asymptotic performance with only one or two errors. These rats made significantly fewer errors than those in experiment 1 on problems 1 to 8 (110.8 compared to 236.8, $P < .05$) and on problems 9 to 16 (19 compared to 69.4, $P < .01$). Each of the four rats in experiment 2 and two of the animals in experiment 1 performed with one or no error in one or more of the discrimination problems in the latter half of the test series. One rat in experiment 2 was given 40 additional two-odor problems. Each problem was solved with only a few errors (mean, 1.9; range, 0 to 17), and criterion performance was achieved with one or no error in 11 of the last 20 problems.

Inasmuch as the rats had received extensive visual discrimination training by the "go, no-go" procedures, improvement in performance over the series of odor problems reflects their learning to discriminate odor pairs and is not confounded by adjustment to or learning about task parameters such as response requirements, reinforcement contingencies, and so forth. Although the data do not reveal the strategy the rats used in achieving near-errorless learning, analysis of individual performance suggested that a "win-stay, lose-shift" hypothesis was in effect. The occurrence of one-trial learning was not dependent on order of stimulus presentation, but was observed when either S^+ or S^- had been presented for the first one to three trials of a problem. In these cases, the animal inhibited responding either to further presentations of a stimulus that was not reinforced (that is, when a response was made to the first presentation of S^-) or to a stimulus different from the one presented on the first few reinforced trials.

Observations of the rats during training suggested that acquisition was correlated with three distinct patterns of behavior. In initial problems, the animals typically did not respond during the first four to eight trials but spent the entire trial period vigorously sniffing at the air inlet port (odor sampling). This was followed by a period when little or no odor sampling occurred but key responses were made immediately after a trial was initiated. Finally, improvement in performance accuracy was correlated with the reappearance of odor sampling. During criterion performance the animal responded on S^+ trials after sampling the stimulus for 1 to 2 seconds. On S^- trials, sampling either continued throughout the trial period or the animal, after some sampling, withdrew from the air inlet port to groom or engage in another activity. The decrease in errors over problems was related to a rapid elimination of the first two stages of this discrimination process (sampling without responding or responding without sampling). Instances of one-trial learning were thus a result of learning to sample the stimulus before responding and adopting a rule for responding (that is, "win-stay, lose-shift") that could be transferred to a new discrimination.

The present results are notable not only because they demonstrate that rats can acquire a learning set for odor stimuli comparable to those achieved by primates in response to visual stimuli, but also because of the rapidity with which the learning occurs. Virtually errorless performance was obtained within the 16-problem series, and most animals reached asymptotic performance within the first five to eight problems. While absolute comparisons with other species are difficult to make because of differences in training procedures (simultaneous presentation of visual stimuli has been used almost exclusively in studies of multiple-problem learning sets), training on a series of several hundred problems has generally been required to achieve equivalent levels of performance in primates and carnivores (*1*, *2*). The rapid learning demonstrated in the present and related experiments (*6*) probably occurs because rats (and other macrosmatic species) are highly prepared to attend to odors and associate odor cues with reinforcement. The present results provide strong support for the recent observations of Seligman (*3*), Garcia *et al.* (*4*), Warren (*2*), and others that stimulus variables having particular relevance for the organism may be as important as phylogenetic status or cortical development in determining performance in many standard laboratory tasks.

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7. Positive and negative trials were programed in a predetermined random order and were initiated by the rat breaking a photobeam directed across the neck of the chamber. Presentation of stimulus pairs and assignment of members of a pair to the positive or negative condition were randomized across animals. Criterion performance was set at 95 percent correct responses in a block of 20 trials. On each problem, errors (responding during a negative trial or not responding during a positive trial) were scored only after the first trial in which a response was made. A 6-second intertrial interval was in effect, and intertrial interval responses produced a 2-second delay before the next trial could be initiated. To ensure that responding would occur in the presence of the stimulus, responses during the first 2 seconds of the trial were ignored.
8. Perfume oils were provided by the Givaudan Corp. through R. F. Dominach. In tests with human observers, odors within a pair were judged to be qualitatively similar, moderately difficult to discriminate, and quite different from members of other floral odor pairs.
9. Two qualitatively different odors (such as jasmine and rose) were used for each problem in experiment 2. The odor stimuli were not diluted, and responding in the presence of the negative stimulus was punished by a 12-second delay before the next trial could be initiated.
10. In these tests, rats performed at chance levels in 100 to 200 trial sessions. Additional control studies demonstrated that after bilateral bulbectomy, rats showed good retention of a visual discrimination but no retention or ability to relearn an olfactory discrimination.
11. We thank H. Lee and R. Gelhard for assistance in conducting these experiments.

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