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VISUAL DISCRIMINATIONS IN THE CAT *

INTRODUCTION

For all their popularity as pets, cats have been conspicuously neglected as experimental animals by behavioral scientists. Yet there are many advantages and even strong reasons for using the cat as a behavioral animal. He is of a convenient size, is easy to maintain, and generally speaking, has a reasonable disposition so that he can be easily handled in the laboratory. Perhaps a more important reason is that a great deal of research has been done by physiologists and anatomists on his nervous system.

Anyone who has attempted to do a behavioral experiment with a cat is soon aware that this animal cannot be trained as easily as a monkey, a rat, or a pigeon. Some of the problems encountered in training cats are: (1) certain responses are preferred to others; (2) certain foods are highly preferred (high protein foods for the carnivorous cat); and (3) they interact with the experimenter probably to a greater extent than any of the other widely used experimental animals. With these things in mind, it can be seen that attempting to place a cat in a situation devised for a pigeon or a monkey is not appropriate; yet this has been the most common approach in behavioral experiments with this animal. For example, many experiments used runways or mazes (Smith, 1936; Kennedy and Smith, 1935; Sperry et al., 1955; Baden et al., 1965; and others), which have been used widely with rats. The monkey testing apparatus developed at Wisconsin (WGTA) was also modified for use with cats, particularly by Warren and his associates (e.g., Warren and Baron, 1956). The shuttle box was another of the more popular types of apparatus that have been adapted for use with cats (e.g., Butler et al., 1957), and appears to be particularly suitable for auditory experiments. Only a few investigators used methods specifically devised for the cat. Guthrie and Horton (1946), for example, made use of a throttlestick device which the animal had to move in order to escape from a cage. A similar operandum has been described recently by Symmes (1963) in which the playful pawing of kittens was used as the response. All these devices have been used more or less successfully by many investigators, but most

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workers using cats as experimental subjects—regardless of the type of apparatus—report that training is lengthy and difficult. With the WGTA and runways, for example, the number of trials per day is small, requiring weeks and even months to reach criterion performance.

Among the behavioral methods so far applied to the cat, the powerful operant methods have been the least used. One reason for this lack is the apparent difficulty in obtaining steady rates of responding with cats pressing a lever or making some other type of simple operant response. The few studies (e.g., Mello and Peterson, 1964; Mello, 1968) which used operant paradigms required lengthy training to achieve stable performance. We wished to train cats to make a variety of visual discriminations rapidly and, in addition, to make use of several of the current operant behavior paradigms. This meant that the animals should generate moderate rates of responding or complete a large number of trials (greater than 30 to 40) per session. A further requirement was that the system be completely automated. The following discussion is a brief description of such an apparatus and training method. Most of the discussion deals with two-choice simultaneous discriminations and visual stimuli. A number of the dimensions of visual stimuli have been examined, including form, brightness, and movement, and data illustrative of the testing procedures and stimulus dimensions are presented below. We have also modified the behavioral apparatus for use with other types of stimuli and training paradigms. For example, thermal sensitivity of the cat's nose is being tested and we are using the apparatus in conditioned suppression paradigms (see Smith, Chapter 6).

REINFORCEMENT

To achieve the first goal of rapid training, it was necessary to find a reward that was appropriate for the cat, one that is highly preferred and easily dispensed. There are a number of suggestions available in the literature, none of which are completely satisfactory. The foods are either difficult to prepare and keep (Hodos et al., 1963; Crawford and Kenshalo, 1965), or cannot be easily dispensed automatically (pieces of beef—spleen, heart, kidney, and so forth). Using a technique worked out for monkeys by Glickstein (personal communication) and the School of Pharmacy at the University of Washington, pellets of varying constituents were manufactured for use with cats. The ingredients that were tried included dried gravy mixes, beef extracts, and pulverized dry cat chow. The latter appeared the most preferred by cats and we finally settled on a mixture of the dry cat chow and binders. Pellets of the proper consistency to withstand ejection by pellet dispensers must have a low fat content. To achieve the low fat requirement, however, meant that only 40 to 50 percent of the pellet could be made of the chow, with the remainder of the pellet made up of binders. This combination turned out an excellent pellet from the standpoint of automation, but the animals would not eat them in sufficient quantities to make them really adequate for use as a reward. They were, however, a great improvement over the liquids and meat tidbits. Pellets were used in the early experiments but recently a system using beef baby food as a reward was developed.[1] The baby food dispenser consists of an air-operated piston and a food reservoir. The piston extrudes a small amount of baby food each time a solenoid valve is operated. The advantage of this latter method is that the animals do not have to be severely food-deprived to work for this reward, and all animals thus far tried have been successfully trained. The success rate with pellets was about 80 percent.

APPARATUS

A number of attempts to teach cats to press a lever (operandum) for milk and then for food pellets were made using an enlarged rat testing chamber. It required considerable patience and a few "tricks" to train them. A typical "shaping" procedure was used in that a reward was delivered by the experimenter to the animal in the test chamber each time a response was made that approximated the desired lever-press. In order to speed this process, the lever was moved from the front wall of the chamber (the typical position in a rat or monkey test chamber) to a position on the test cage floor, close to one of the forepaws of the animals. This greatly decreased the amount of time necessary to train the animals to depress the pedal and produced ,good rates of responding on high-density reinforcement schedules; that is, when rewards were delivered at frequent intervals during pedal pressing. Visual stimuli were presented on the front wall of the chamber above the food cup and response pedal. Although several animals were successfully trained to press the pedal, not one was brought under the control of the visual stimuli. Different stimuli which when presented signaled the availability (positive stimulus) or the unavailability (negative stimulus) of food for a pedal press did not control pedal pressing. Observation of the animals disclosed that they never looked away from the food cup except when attempting to escape from the test chamber. Changing the level of the test cage illumination, however, could be used as a stimulus to control responding. For the types of visual discriminations we wished to teach the cat, however, this system was clearly not adequate. These observations led to the design and construction of a new testing apparatus which placed the stimuli, operandum, and food terminal in close proximity. This not only shortened training time but assured that the animals would observe the test stimuli.

The details of the apparatus are shown in Figure 1. The stimuli, reward terminal, and operanda are located at the end of a short Plexiglas cylinder which is mounted on the outside of the test chamber. The animal sits in the test chamber and thrusts its head into the cylinder (see Fig. 1, A) through a hole in the wall of the chamber. The operanda, consisting of two nose keys, the visual stimuli, and the food terminal are located at the outer end of the cylinder. This

[1] The piston pump feeder was modified from a system designed by T. Crawford and G. Oliff, Department of Psychology, Florida State University.

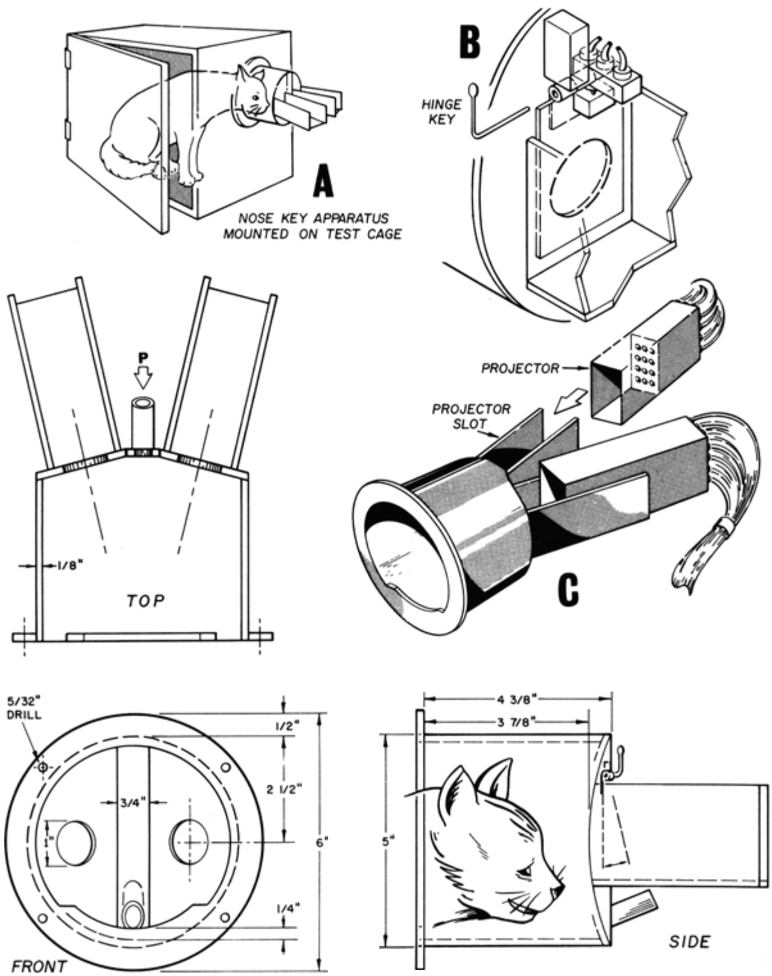

Fig. 1. A-test chamber with test apparatus mounted on outside; B-rear view detail of nose-key showing quick-disconnect hinge; C-cradles for in-line projectors are shown mounted on the back of the test cylinder. The remainder of the figure lists the dimensions and shows construction details. All parts are made of Plexiglas and are cemented together with chloroform.

arrangement quickly orients the animals to the stimuli, reward terminal, and operanda at the same time. Responses consist of pressing the key with the nose.

Figure 1 shows the apparatus set up for use with pellet rewards, but recently the baby food delivery tube has replaced the pellet dispenser tube (see Fig. 1, P). Projectors or other stimulus generators are placed behind the nose keys. In the early stages of training, the animals may attempt to operate the keys with their forepaws or attack the keys when they do not receive a reward. To minimize the ability of the animals to place their paws in the cylinder, a Plexiglas disc was made which has a 3- to 4-inch aperture. This annulus is screwed to the inside of the test chamber over the opening to the plastic cylinder, reducing its effective diameter. With this plate in place, the animal cannot place both its head and forepaws in the tube simultaneously. The annulus is removed when training has progressed to a stable level, and the cat is no longer attempting to paw the keys.

The nose keys (see Fig. 1, B) are made of thin, clear or frosted Plexiglas with a quick-disconnect hinge which facilitates removal for cleaning. None of the dimensions appear to be critical, but those shown in the figure have proven to be very convenient.

TRAINING PROGRAM

The program devised for use with the apparatus is a modification of a program devised by Glickstein et al. (see Chapter 11) for use with monkeys. All programming of stimuli and recording of responses is automatic. A discrete trial procedure is used which consists of presenting two visual stimuli simultaneously, one on each key. If the cat depresses the nose key displaying the correct (positive) stimulus, a reward is delivered and the stimuli are turned off for a short time period before the next trial is presented. If the incorrect (negative) stimulus is chosen, no reward is delivered and the stimuli are turned off until the next trial.

The stimuli appear in a random left-right sequence, with the restriction that the positive stimulus does not appear on more than four consecutive trials in the same left-right position. The intertrial interval (ITI) is adjustable, but short intervals (2 to 4 seconds) seem to work best. The ITI after an incorrect response is 4 seconds and after a correct response is 2 seconds. In early training stages, rapid responding is maintained using a 2-second ITI, regardless of stimulus choice. The animal is required to withhold responding during the ITI; responses during the ITI recycle the ITI timer. Thus, the animal must wait out the full time interval counted from his last response, not from the last trial. To eliminate position habits—responding to one side only regardless of stimulus position—a further restriction in the programmer limits the number of consecutive responses on the same key to eight. Beyond that number, the circuit generating random left-right positions is disabled and the correct stimulus appears only on the side opposite the position habit. The correct stimulus remains in this position until the animal responds to the nonpreferred side.

TRAINING PROCEDURE

After the animal has been reduced to 80 percent of ad lib weight, it is placed in the test chamber and observed through a small window. When the cat places its head in the plastic cylinder (Fig. 1, A), a reward is delivered to the food terminal (Fig. 1, P). Within a few minutes, the animal is holding its head in the cylinder for periods lasting several seconds. At this point, head movements that approach one nose key are rewarded, and finally, only depression of the nose key with the nose is rewarded. This procedure of rewarding successive approximations to the desired response ("shaping") is extremely rapid and usually requires only 5 to 10 minutes. Occasionally, an animal will require as many as two or three "shaping" sessions, but much of the rapidity of training appears to depend on the technique of the trainer; some people are better at it than others.

Usually 25 to 50 reinforcements are sufficient for food terminal and nose key training. When the cats have learned the response, they are permitted to make 200 to 400 responses on a single key before the random left-right position circuit is activated. The animals are then given several daily sessions of training to learn to discriminate between an illuminated key and a dark key which vary in position. Responses on the lighted key (positive stimulus) are rewarded and responses on the dark key (negative stimulus) are not (a simple "brightness" discrimination). Figure 2 shows the rapidity with which the animals are able to learn this simple discrimination with food pellets as the reward. In several cases, the "brightness" discrimination was learned (criterion of greater than 90 percent correct) on the first training day (e.g., see PG, CF7, CF9, and CF12 in Fig. 2).

Figure 3 (upper portion) shows the same simple problem, but with animals rewarded with beef baby food instead of food pellets. Only 3 to 4 days were required from the first exposure to the apparatus to when most of the animals reached a high level of performance on this discrimination problem. The total time invested in each animal to this point (excluding feeding, cleaning, weighing, and so forth) is approximately one hour. In Figure 3, the first number on the abscissa for each animal indicates the number of days the animals were "shaped" in the apparatus before being given the light-dark problem.

The lower portion of Figure 3 shows a similar discrimination problem, but in this case a line oscillating at 25 cycles per second was the positive stimulus. A dark or blank key was the negative stimulus. The moving lines were produced by miniature cathode ray tubes placed behind the nose keys. A further descrip-

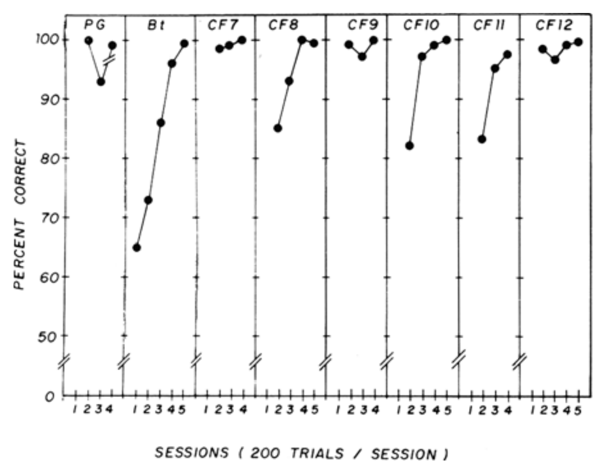

Fig. 2. Simple light-dark discriminations with cats rewarded with food pellets.

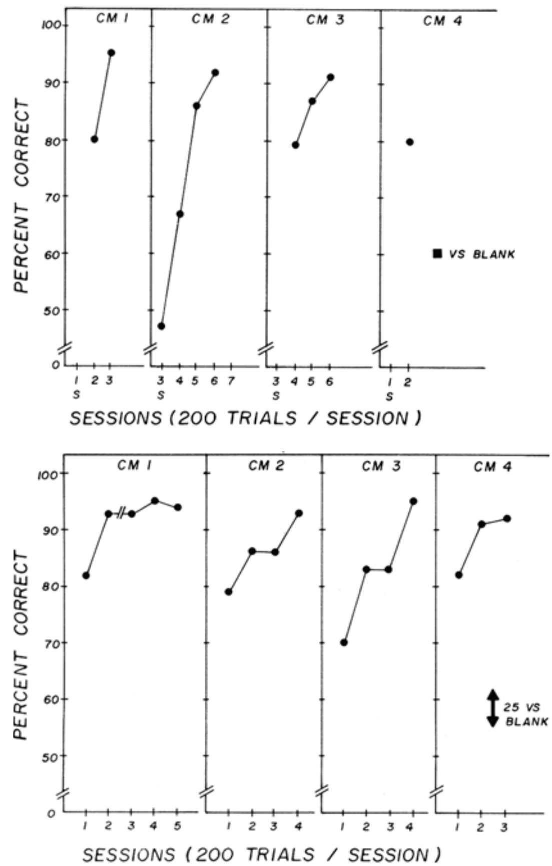

Fig. 3. Upper: Simple light-dark discrimination behavior of cats rewarded with beef baby food. The first number on the abscissa for each animal notes the number of days needed to key-train the animal. Lower: Early stages of real-movement discrimination training in which the positive stimulus was a line oscillating vertically at 25 cps and the negative stimulus was a blank key.

tion of the stimulus display is given in the last part of this chapter.

A criterion of 90 percent correct for three consecutive days was at first required before the next discrimination problem was presented. Frequently, however, the animals' performance was clearly above chance (50 percent correct) for a considerable time but below 90 percent correct, and it was necessary to adjust the criterion accordingly. For example, several animals performed at 85 percent correct or better for several days (see Fig. 7), but did not appear to be improving. They were performing consistently above chance, so a modified criterion was used. In these cases, the animals were advanced to the next discrimination problem when they had three consecutive daily sessions on which they scored between 87 and 90 percent correct. These difficulties are typical of discrete trial procedures and serve to point up the arbitrary nature of the choice of a criterion. In some difficult discriminations, animals may never reach a level of 90 percent correct but may perform consistently at 75 percent correct or even lower.

FORM DISCRIMINATIONS

The data in Figure 4 shows a typical animal and its performance on a series of pattern discriminations. Note that the first problem (square versus blank) is also shown in Figure 2 (CF9) and represents the initial exposure to the testing situation for this animal. Learning was rapid on all problems with a high degree of transfer from one problem to the next. In the first form discrimination problem, an inverted triangle is presented on one key and an upright triangle on the other. A brightness difference is correlated with the correct triangle orientation. The inverted triangle is completely illuminated, whereas just the outline of the upright triangle is illuminated. In the second problem, the brightness cue is absent with both triangles completely illuminated, and the third problem is just the reverse of the first problem with respect to the brightness difference. This sequence of problems demonstrates that the animals are responding to the shape of the stimulus and not some other dimension. The poor performances on days 14, 22, and 46 were due to failures in the pellet dispenser. When the triangle discriminations were completed, the next problem was presented and consisted of horizontal and vertical lines. The last portion of Figure 4 shows the performance of this animal on this problem.

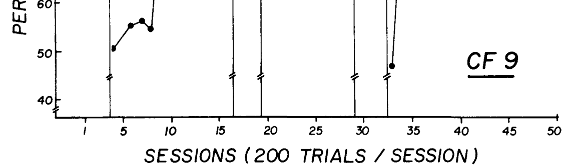

Fig. 4. The performance of cat CF9 on a series of form discriminations. The small figures at the top of the figure depict the pair of stimuli that were presented simultaneously to the animal. In all cases, the left figure of the pair was the positive stimulus.

"FADING" AND BRIGHTNESS MATCHING

When an animal is having difficulty making a discrimination, it is sometimes helpful to add a cue to the correct stimulus to aid in the discrimination. In addition to a distinctive pattern (e.g., circle versus a square), a brightness cue might be added to the correct stimulus (e.g., Terrace, 1963; Sidman and Stoddard, 1967). The situation confronting the animal might be a circle and a square presented simultaneously, with the circle (positive stimulus) being brighter (greater luminance) than the square. In the early stages of training, the brightness is correlated with the correct pattern. Each time the animal presses the key displaying the correct pattern (the circle which has the greater luminance of the two stimuli), the intensity of the incorrect stimulus is increased by a small increment. If the animal makes an incorrect choice, the intensity of the incorrect stimulus is decreased by a small increment. The animals first respond to the stimuli on the basis of brightness (luminance) differences. As training progresses, the brightness cue is "faded out" leaving only the shape or form of the stimulus as the cue for making a correct response (see Chapter 11). The brightness of the correct stimulus is usually recorded with a recording milliammeter and produces records simular to those shown in Figure 5 (also see Luschei and Saslow, 1966). The data shown in Figure 5 were obtained from a modification of the system described above.

The modification was the use of a luminance difference without the pattern cue. In this case, the stimuli on both nose keys have the same form (shape), but one stimulus is set at some constant intensity and is the correct (rewarded) stimulus. The negative stimulus is a lower light intensity. Each time the animal responds to the dimmer or incorrect stimulus, the incorrect stimulus intensity is decreased, increasing the luminance difference between the two stimuli. Responses to the positive stimulus increase the intensity of the negative stimulus by a small amount, decreasing the luminance difference between the two stimuli. The intensity is adjusted by changing the voltage to the bulbs with a potentiometer which is rotated by a bidirectional motor. The use of a potentiometer to control intensity, of course, also results in chromatic changes in the lamps, and this procedure, therefore, is usable only as a rough evaluation of the brightness matching abilities. A recording milliammeter records the position of the potentiometer and hence, the intensity of the incorrect stimulus. When the two are equal in intensity, responses to each are equally probable and an oscillating horizontal line will be produced on the recording milliammeter as shown in Figure 5. The horizontal dashed line shows the intensity of the negative stimulus which would be an intensity match to the positive stimulus. The figure shows the records of an

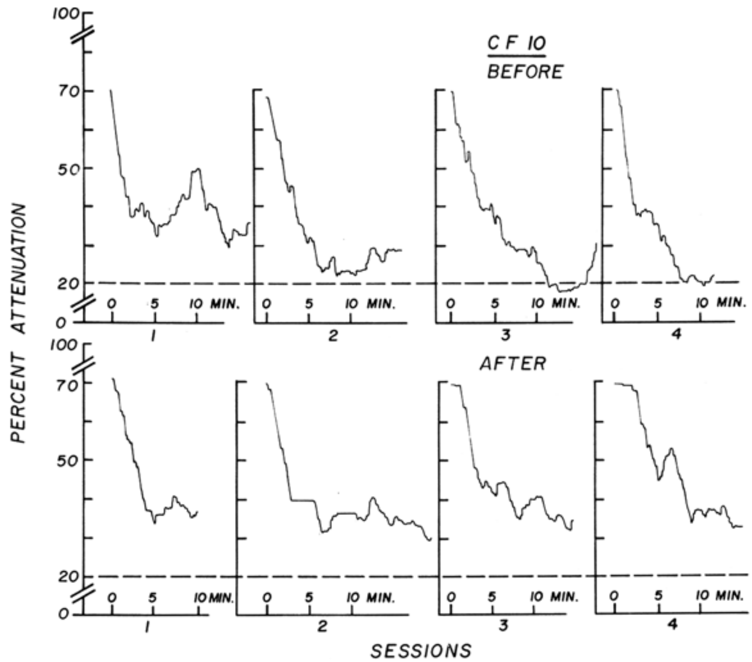

Fig. 5. Brightness matching in a cat (CF10) before and after a massive striate cortex lesion was made. See text for details.

animal in this brightness matching situation on four consecutive daily sessions. The top portion of the figure shows that on the first day the animal does not do well in matching the brightness of the two keys, but on subsequent days he closely approximates a brightness match. The lower portion of the figure shows the same situation with the same contingencies for brightness matching, but these measurements were taken after striate cortex lesions were made in this animal. When this animal was tested on a simple brightness discrimination—an illuminated versus a dark key—no impairment was seen when compared to presurgery performance. The brightness matching paradigm, however, showed that presurgical levels of matching brightness were not reached. It is likely that this animal had a large region of blindness in the center of his visual fields and was using peripheral vision in attempting to match brightness. These data demonstrate the usefulness of making a variety of measurements in animals with brain lesions. If brightness matching abilities had not been evaluated, we would not have seen any impairment in intensity discrimination. In many studies, the training procedure is so lengthy and difficult that the investigator is content to be able to make one or two tests of each animal's abilities. With the apparatus and training program described, many different tests may be used with relatively little time needed for testing each animal. (The use of the fading procedures in teaching brain-damaged animals different pattern discriminations is discussed in detail by Glickstein et al., in Chapter 11.)

DISCRIMINATION OF REAL MOVEMENT

It is clear from the experiments of Hubel and Wiesel (1965) and others that movement is a very potent visual stimulus. Except for the early experiments of Kennedy and Smith (1935), very little behavioral work has been done on visual movement detection in the cat (Berkley, 1969). In order to study this particular aspect of vision, the discrimination apparatus previously described was modified in a simple way. The pattern projectors behind the nose keys were replaced with 1-inch cathode ray tubes (CRT). The keys were changed to clear Plexiglas so that the tube displays could be seen through the keys. Lines or dots were produced on the CRTs, and were made to oscillate at a linear rate by the application of a triangular wave form to the vertical deflection amplifiers of the CRT. The rate of movement was controlled by changing the frequency of the triangle wave, and the extent of movement was controlled by adjustment of the amplitude of the wave. In the experiments reported, the extent of the movement was limited to 1 cm on the face of the CRT. Using 7 cm as an estimate of the position of the cats' eyes relative to the CRTs, a movement of 1 cm is equivalent to approximately eight degrees of visual angle. Since the heads of the animals are not fixed in any way, this is just an approximation; however, after being trained in the apparatus for several weeks, the cats do maintain a relatively fixed head position.

The training program was the same as described earlier. In order to present

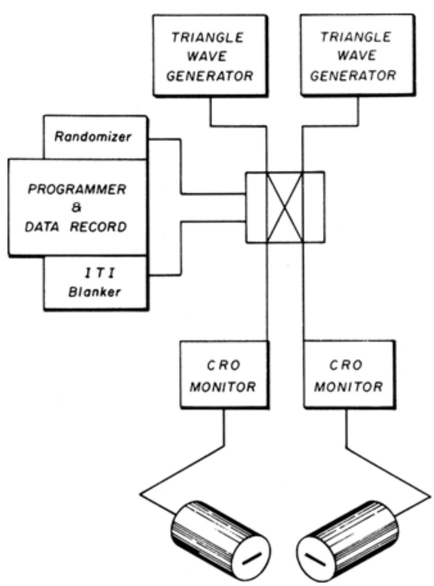

Fig. 6. Block diagram of movement programming apparatus. Cylinders at bottom of figure represent one-inch cathode ray tubes.

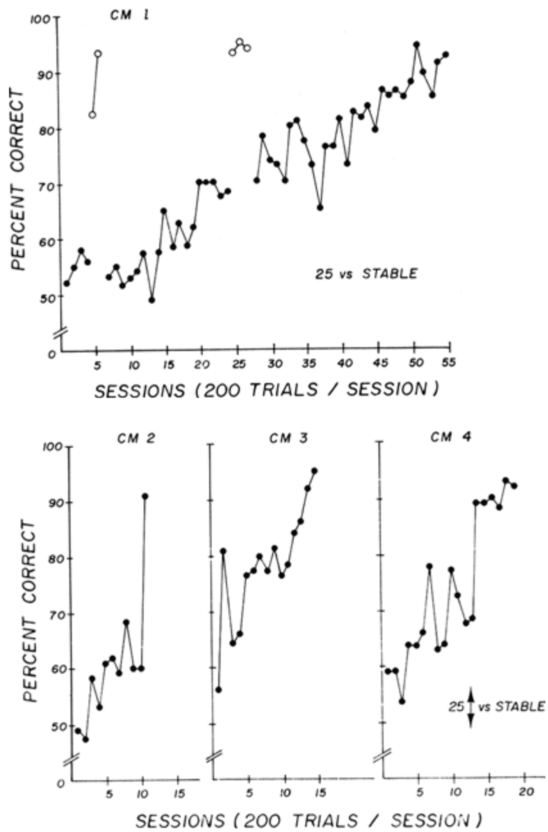

Fig. 7. The performance of several cats on the initial movement discrimination problem. In all cases the positive stimulus was a line oscillating vertically at 25 cps and the negative stimulus was a stationary line. See text for further details.

blank displays during the intertrial interval, a dc offset voltage was applied to the vertical amplification system during the ITI so that the display was deflected off the CRT. The triangle wave generators were monitored continuously on slaved oscilloscopes (see Fig. 6, CRO monitor), which were located near the programming equipment where they displayed the stimuli being presented in the test chamber. A general diagram of the apparatus is shown in Figure 6. The programmer and randomizer determined the left-right position of the displays and the input signals to the display CRTs were routed through a special switch box. The switch box channeled the triangle wave inputs to the appropriate CRT as determined by the randomizer and programmer. The data that follow involve only simple discriminations that consisted of selecting the key in front of the CRT that had the moving (positive) stimulus. In all cases, only one display was moving; the other was either stationary or blank. The next two figures show the results of training animals to press the key in front of a line moving at a rate of 25 cm per second (200 degrees per second). The animal's task was to choose the oscilloscope tube which had this stimulus on it. The bottom portion of Figure 3 shows the rate at which the animals learned this simple problem. The next problem in the sequence was to present a stationary line on the previously blank CRT. The animal was presented with one oscilloscope tube which had a line moving at a rate of 25 cm per second and another CRT on which there was a line which was stationary. The position of these two stimuli varied randomly as previously described. Figure 7 shows the performance of animals on this problem. All animals started with a low percentage of correct choices but improved rapidly. Generally, within 10 or 12 days the animals reached criterion. CM1 in Figure 7 took 55 sessions (approximately 2 months) to learn this simple problem. On day 5 of this problem, the previous problem (25 versus the blank key) was introduced to see if the apparatus was functioning properly (open circles, Fig. 7). On the first day of the rerun, the animal produced 82 percent correct choices, and on the next day, 93 percent. The 25 versus the stationary problem was then presented again. The open circles later in the curve (days 26 to 28) represent another rerun of the simpler problem. We then returned him again to the 25 cm per second versus stationary line problem and continued training another 25 or 30 days until the criterion was achieved. Of the 8 or 10 animals we have trained on these problems, this particular cat, CM1, is by far the slowest. The next figure (Fig. 8) shows the performance of two animals on a number of movement discriminations involving different rates and meridians. The arrows on the figure indicate the meridian in which the line stimulus moved. A dot next to the arrows indicates that the moving stimulus was a dot rather than a line. The numbers beneath the arrows (e.g., 5 versus S, 3 versus S) indicate the rate of stimulus movement in centimeters per second. Note that with one exception, all animals are performing well above chance early in training but require a relatively long time to reach a 90 percent correct criterion. The original criterion of 2 consecutive days performance at better than 90 percent correct was eased, as described earlier. Any behavior that is significantly different from chance is adequate and the arbitrary choice of 90 percent may, under some circumstances, be inappropriate. For example, some animals performed for weeks in the 80 to 90 percent correct range. When slower rates of movement are presented, an even lower percentage of correct choices may be seen consistently. By presenting slower and slower rates and getting lower and lower percentages, thresholds may be obtained in this way. The last figure (Fig. 9) shows the behavior of two other animals making movement discriminations. The lower right-hand portion of the figure is the behavior of subject CM4 in response to a line stimulus moving at 3 cm per second in the horizontal meridian. The open circles indicate days on which the animal was presented with the same stimuli but moving in the vertical meridian. Note the slight improvement the first time this was done. The problem of "attention" is worth mentioning here. Frequently, the dimension of a stimulus that is being investigated is not the same dimension to which the animal is responding (Reynolds, 1961). In the case of movement detection, a stimulus dimension that may confound the results is position. That is, it is possible that the animals were making the discrimination on the basis of difference in position of the moving stimulus (line or dot) from one trial to the next rather than to the dimension of movement. Two findings, however,

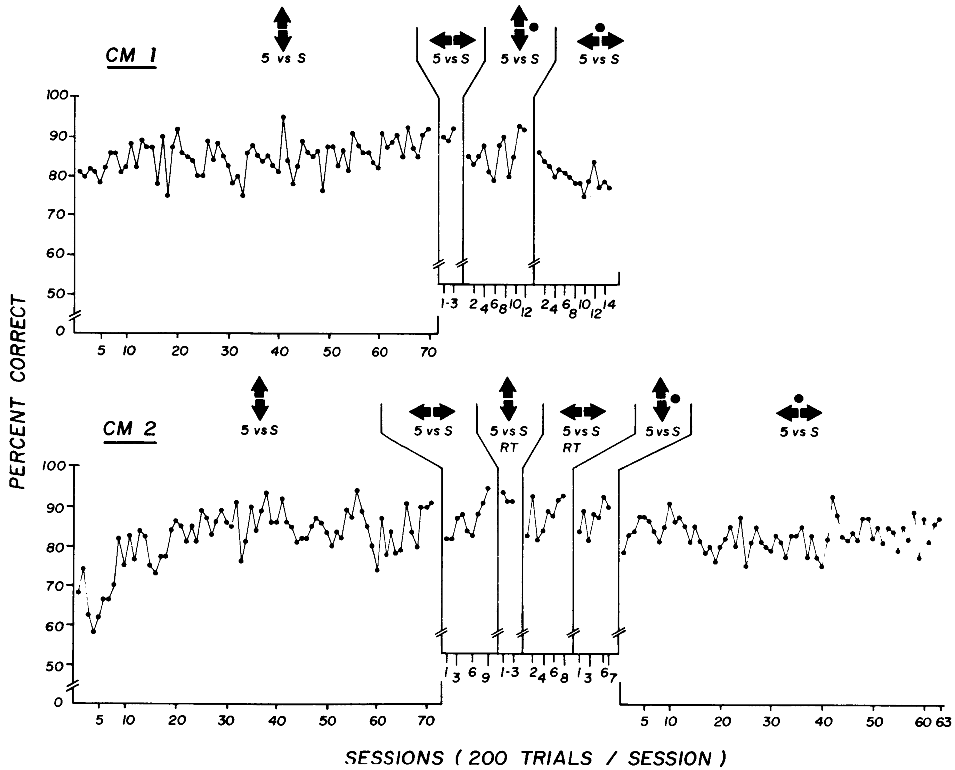

Fig. 8. The performance of two cats (CM1 and CM2) on a series of movement discrimination problems. The arrows indicate the direction of movement of the positive stimulus. The negative stimulus was a stationary line (S). The number below the arrows indicates the rate of movement in cps. See text for further details.

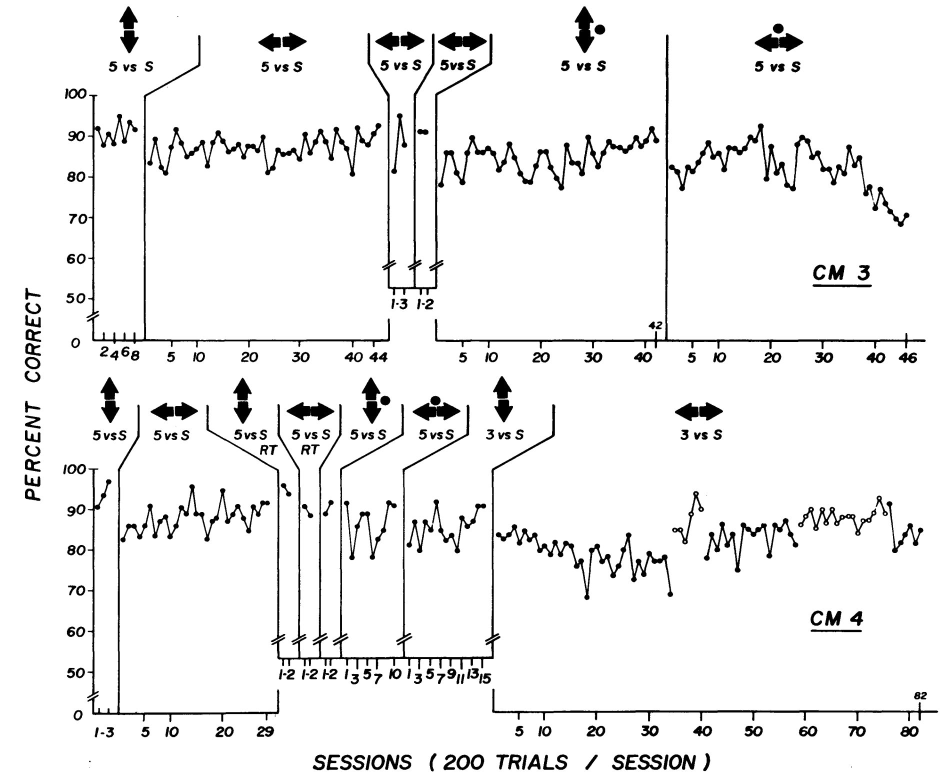

Fig. 9. The performance of two cats (CM3 and CM4) on a series of movement discrimination problems. The arrows indicate the direction of movement of the positive stimulus. The negative stimulus was a stationary line (S). The number below the arrows indicates the rate of movement in cps. See text for further details.

tend to rule out this explanation. The first is that there is a very high degree of transfer when the movement meridian is changed from vertical to horizontal, and second, we have changed the position of the stationary stimulus on the CRT from time to time without observing any decrement in performance. It is possible that the small decrement in performance seen in some animals (e.g., CM2 and CM4) when the meridian is changed from vertical to horizontal is due to a slight position effect and is a subject for future study.

CONCLUDING REMARKS

With the proper equipment and reward, cats can be trained to make difficult discriminations with relative ease. Several important facts have emerged from attempts to train these animals. One is the importance of using a highly preferred reward and another is the necessity of placing operandum, stimuli, and reward in close proximity. Finally, careful control of the animal's diet is necessary to achieve a sufficient level of motivation to speed training.

One final point about the apparatus is worth mentioning. The most troublesome aspect of the system is proximity of the stimuli to the eyes of the animal and uncontrolled head position. Head position becomes a problem when attempting to assess the limits of acuity and movement detection. With the stimuli being so close to the animals, any small changes in head position will drastically affect visual angle.

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