Potentiation, Overshadowing, and Blocking of Spatial Learning Based on the Shape of the Environment

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Rats were trained in Experiment 1 to find a submerged platform in 1 corner of either a rectangular or a kite-shaped pool. When the walls creating this corner were a different color than the opposite walls, then learning about the shape of the pool was potentiated in the kite but not in the rectangle. Experiments 2–4 revealed that learning about the rectangle can be overshadowed and blocked when information about the wall color indicates the location of the platform. The results mimic findings that have been obtained with Pavlovian conditioning, and they challenge the claim that learning about the shape of the environment takes places in a dedicated geometric module.

Keywords: spatial learning, overshadowing, blocking, potentiation

Theories of associative learning differ considerably in detail, but they share the common assumption that stimuli must compete for the control they acquire over behavior (e.g., Rescorla & Wagner, 1972). Overshadowing (Pavlov, 1927) provides one example of an effect that is consistent with this assumption. If two stimuli are simultaneously paired with an unconditioned stimulus, then it is often found that responding during one of them will be less than if it had individually been paired with the unconditioned stimulus. Further evidence of the competition between stimuli can be found in studies of blocking (e.g., Kamin, 1969a, 1969b), which have shown that the effects of overshadowing can be enhanced by additional training with one of the stimuli by itself before conditioning with the compound. Overshadowing and blocking have been revealed in fish (Tennant & Bitterman, 1975), birds (Mackintosh & Honig, 1970), and mammals (e.g., Kamin, 1969a, 1969b). Moreover, these effects have been revealed with a wide range of stimuli in a variety of procedures. It would thus seem, for both theoretical and empirical reasons, that a competition between cues for the control of behavior is a fundamental and pervasive characteristic of learning in animals.

A challenge to this conclusion comes from spatial learning experiments in which animals were required to find a hidden goal by reference to the shape of their environment. Pearce, Ward-Robinson, Good, Fussell, and Aydin (2001) trained rats to find a submerged platform that was located in one corner of a triangular swimming pool. This ability was not impaired at all if a beacon was attached to the platform. In other words, the beacon did not overshadow spatial learning based on the shape of the pool. Similar failures to find overshadowing by a landmark have been observed in a rectangular test environment with rats (Hayward, Good, & Pearce, 2004; Hayward, McGregor, Good, & Pearce, 2003) and pigeons (Kelly, Spetch, & Heth, 1998). There have also been reports of a failure of a landmark to block spatial learning based on the shape of the environment (Hayward et al., 2004; Pearce et al., 2001; Wall, Botly, Black, & Shettleworth, 2004). Other studies have been said to show that learning about the shape of the environment is unaffected by the presence of landmarks or other discrete features, but interpretation of their findings is hampered by the absence of appropriate control conditions (e.g., Cheng, 1986; Sovrano, Bisazza, & Vallortigara, 2003; Tommasi & Vallortigara, 2000).

A number of authors have argued that these findings imply that information about the shape of the environment is processed in a dedicated geometric module that is impenetrable to any other sort of information (e.g., Cheng, 1986; Gallistel, 1990; Wang & Spelke, 2002, 2003). As a consequence, if a goal is hidden consistently in the same corner of a rectangular arena, learning about its location relative to the shape of the environment is assumed to progress independently of any additional learning that might take place with other stimuli. In other words, because of the impenetrability of the geometric module, it follows from the proposals of Cheng and Gallistel that learning based on the geometric properties of the environment will not be governed by the principles that apply to other types of learning.

The experiments considered thus far have examined the interaction between the shape of the environment and discrete landmarks that were located at or near the goal. Several other experiments have examined how spatial learning based on the shape of the environment is affected when the color of the walls creating the shape also indicates where the goal can be found. Although the results from these studies are conflicting, they are of interest because they appear to challenge the proposals of Cheng (1986)
and Gallistel (1990). Gray, Blomfield, Ferrey, Sptech, and Sturdy (2005) trained chickadees to find food hidden in one corner of a rectangular enclosure. For one group, three of the walls were white and one was blue, and food was hidden in a corner where a blue wall met a white wall. Subsequent test trials in a white enclosure revealed that the shape of the enclosure gained less control over searching for the goal in this group than in another group for which the four walls had been white during the training stage. An implication of this result is that learning about the shape of the enclosure was overshadowed by making one of the walls a distinctive color. A very different outcome, using a related design, was reported by Graham, Good, McGregor, and Pearce (2006), who demonstrated that the color of the walls may actually potentiate learning about the position of a goal relative to the shape they form. Rats were trained to find a submerged platform in a kite-shaped pool that was constructed from two long and two short walls and with two right-angled corners where the long and short walls met. The platform was consistently located in the same right-angled corner. For an experimental group, the walls of this corner were always the same color, say black, and the opposite walls were always white; for control groups, either the color of the pairs of walls varied randomly from trial to trial or the four walls were of the same color. Subsequent trials in a pool of uniform color revealed a stronger preference for searching in the correct corner by the experimental group than by the control groups. An implication of this finding is that learning about the position of the platform relative to the shape of the pool was potentiated when the color of the walls also indicated where the platform could be found. Finally, two studies using either goldfish (Vargas, López, Salas, & Thinus-Blanc, 2004) or pigeons (Vargas, Petruso, & Bingman, 2004) have found that the shape of a rectangular arena gained control over searching for a hidden goal, even though it could be found by referring to information provided by the color of the walls. Both of these studies lacked an appropriate control condition, which makes it difficult to assess if the color of the walls had any impact on learning based on the geometric cues.

The results from Gray et al. (2005) and Graham et al. (2006) contradict the proposals of Cheng (1986) and Gallistel (1990) and imply that nongeometric information can influence learning based on geometric cues. However, because the two studies revealed conflicting outcomes it is important to confirm their reliability before firm theoretical conclusions are drawn from them. Our Experiment 1 was conducted, therefore, to determine whether the different results reported by Gray et al. and Graham et al. can be found with the same species and the same task, but with two different shapes. The experiment revealed clear evidence of potentiation in a kite-shaped arena and an indication of the opposite effect in a rectangular arena. Because the latter finding contradicts a substantial body of experimental findings, we conducted additional experiments to demonstrate that it is reliable.

**Experiment 1**

In the experiment by Gray et al. (2005), hungry chickadees had to find food buried in one corner of a rectangular arena with three white walls and one blue wall, whereas in the experiment by Graham et al. (2006), rats had to find a submerged platform in a kite-shaped pool of water with two black walls and two white walls. Experiment 1 was designed to test, of the many differences between these studies, whether the different shapes of the arenas were responsible for the contrasting outcomes of the experiments.

Two of the four groups in the experiment were trained and tested in a similar manner to two groups in the Graham et al. (2006) study. A black-and-white-kite group was required to find a submerged platform that was located in a right-angled corner of a kite-shaped pool. The two walls creating this corner were white, and the remaining two walls were black. A white-kite group was trained in the same way except that the four walls of the pool were white. On the basis of the findings reported by Graham et al., we expected the shape of the pool to gain greater control over searching for the platform in the black-and-white-kite group than in the white-kite group. To test this prediction, both groups were placed for 60 s in a kite-shaped pool with four white walls and with the platform removed. It was anticipated that the black-and-white-kite group would prefer to spend more time than would the white-kite group searching in the corner where the platform was originally located.

The remaining two groups were trained and tested in a similar manner to the two groups just described, except that the shape of the pool was rectangular. The black-and-white-rectangle group was required to find the platform in a corner constructed from a white short wall that was to the left of a white long wall; the two remaining walls were black. The white-rectangle group was trained to find the platform in the equivalent location in a rectangle with four white walls. Both groups then received a test trial in a rectangle with four white walls. On the basis of the findings by Gray et al. (2005), we expected the black-and-white-rectangle group to spend less time searching in the geometrically correct corners of the rectangle than did the white-rectangle group.

Graham et al. (2006) anticipated that during the training stage of their experiment the experimental group would find it much easier to locate the submerged platform than would the two control groups. In an attempt to equate the difficulty of this training for the three groups, they therefore used a beacon as an additional cue to indicate where the platform could be found. For similar reasons, a beacon was attached to the platform for every training trial for the four groups of the present study. In keeping with the experiments mentioned earlier, there was no indication in the study by Graham et al. that the beacon disrupted learning based on the other cues.

**Method**

**Subjects.** The subjects were 40 naive, male hooded Lister rats (Rattus norvegicus) supplied by Harlan Olac (Bicester, Oxon, England). The rats were housed in pairs in a light-proof room in which the lights were on for 14.5 hr each day. They were tested at the same time on successive days, 5 days a week, during the period when the lights were on in their holding room. They were randomly assigned to the four groups in equal numbers at the start of the experiment.

**Apparatus.** The experiment took place in a white, circular fiberglass pool that was 2 m in diameter and 0.6 m deep. It was mounted on a platform 0.6 m above the floor in the middle of a room that was 4.0 m × 3.0 m × 2.3 m high. The pool was filled to a depth of 27 cm with water that was rendered opaque by the addition of 0.5 L of white opacifier E308 (Roehm and Haas, U.K., Ltd, Dewsbury). The water was changed daily, and its temperature was 25 °C (±2 °C). A video camera with a wide-angle lens was fixed 1.75 m above the center of the pool. The lens of the camera was situated 25 cm above a 30-cm-diameter hole in a white circular ceiling with a diameter of 2 m. The image from the camera was relayed to a monitor in the northeast corner of the experimental room and to recording
equipment in an adjacent room. The rats’ movements were analyzed using Watermaze software (Morris & Spooner, 1990). In the circular ceiling above the pool were eight 45-W spotlights, 22.5 cm in diameter, that were arranged at equal distances in a circle with a diameter of 1.6 m. The spotlights were illuminated throughout the experiment. The escape platform, which was made from clear Perspex, was 10 cm in diameter and was mounted on a column. The surface of the platform was composed of a series of concentric ridges. The column stood on the floor of the pool, and the platform surface was 2.5 cm below the surface of the water. A light blue, 1.5-m-high curtain hanging from the ceiling was drawn completely around the pool and fell 25 cm beyond the pool’s edge. The room was additionally illuminated by four 1.53-m strip lights that were attached end to end in pairs on opposite 4-m walls of the room, running parallel to the floor and 75 cm above the floor. There was a door in the center of one of the 3-m walls. The center of the door defined north for the purposes of the experiment.

To create the two different shapes, four acrylic boards were suspended vertically in the pool from bars that extended over the pool’s edge. The boards were 0.59 m high and 2 mm thick; the two long walls were 1.8 m long, and the two short walls were 0.9 m long. The overlap of the bars that supported the boards at the edge of the pool resulted in the tops of adjacent panels differing by 2 cm. The height of the top of a given panel above the surface of the water thus varied randomly from session to session between either 33 or 35 cm. The four corners of the both arenas were in contact with the wall of the circular pool. When the boards were arranged in the shape of a kite, the arena contained two right-angled corners, an acute-angled corner, and an obtuse-angled corner.

Throughout training, the center of the platform was 25 cm from the appropriate corner on a line that bisected the corner. A beacon was attached to the platform for every training trial. The beacon was a plastic rod with a diameter of 1 cm and with alternating black and white hoops with a width of 1 cm along its entire length. A white plastic disk, 3 cm in diameter and 0.5 cm thick, was attached to the top of the rod 23 cm above the surface of the water. The rod was attached to the platform 2.5 cm from its edge at the point that was farthest from the corner.

Procedure. Rats were transported to the test room five at a time in light-tight boxes, which were placed on a shelf in an adjacent room. All rats received 13 sessions of training. There were four trials in each session, and for each training trial rats were required to escape from the pool by swimming to the submerged platform. The platform was situated in the right-angled corner where the short wall was to the left of the long wall for all subjects. The two walls creating this corner were white, and the opposite two walls were black for the black-and-white-kite and the black-and-white-rectangle groups. All four walls were white for the white-kite and the white-rectangle groups. Rats were released by being lowered gently into the pool facing the center of one of the walls. The sequence of walls from which they were released varied randomly from session to session with the constraint that each wall was used once in every session. Throughout each trial, rats were observed on the monitor. If a rat failed to find the platform within 60 s, the experimenter placed a finger approximately 5 cm in front of the rat’s nose and guided it to the platform. Rats were allowed to remain on the platform for 30 s before they were removed from the pool. After a trial, the rats were dried gently and returned to the light-tight box where they remained until the other four rats had received a single trial in the pool. This cycle was repeated until all rats had received four trials. After the five rats had each received a single trial, the arena was rotated clockwise through 90°, 180°, or 270°. The arena was always oriented along a north–south or east–west axis. The orientation at the start of a session varied randomly, and within a session the arena was oriented only once in each of the four possible directions. For the white-rectangle group, the platform occupied one of the two candidate corners for a randomly selected two trials in each session and the other corner for the remaining two trials. The first three trials of Session 14 were conducted in the same manner as were the preceding sessions. All rats then received a test trial in a pool of the same shape as during training, but all of the walls were white. Each rat was released from the center of the pool and was allowed to swim for 60 s in the absence of the platform.

The escape latency—the time taken by the rat to place four paws on the platform after it was released into the pool—was recorded on every trial. A record was also made of whether a rat first entered a correct or an incorrect right-angled corner after being released. A correct corner was defined as the one containing the platform in the kite or the one containing the platform and the diagonally opposite corner in the rectangle. For ease of exposition, we refer to a response of entering a correct corner without previously entering an incorrect right-angled corner as a correct choice. An entry into a corner was deemed to have taken place when the subject’s snout entered a quadrant of a circle with a radius of 40 cm and with its center at the point where the walls creating the corner met. To compare the results from the test trial in the two arenas, we measured the time that rats spent in circular search zones that were located in the correct and incorrect right-angled corners. The centers of these zones, which had a radius of 15 cm, were situated 25 cm from the corner on a line that bisected the corner. Because there were two correct and two incorrect search zones in the rectangle, and only one incorrect search zone in the kite, the mean amount of time spent in each type of zone was used for the presentation and analysis of the results from the rectangle group.

**Results**

A Type I error of $p < .05$ was adopted for all experiments. The left-hand panel of Figure 1 shows the group mean escape latencies for every session. In general, escape latencies were shorter in the black-and-white arenas than in the white arenas and shorter in the kite than in the rectangle. A two-way analysis of variance (ANOVA) of individual mean escape latencies for the 14 sessions combined was conducted with the factors of shape of the arena and color of walls (whether they were black and white or just white). There was a significant effect of shape, $F(1, 36) = 6.70$, and of color, $F(1, 36) = 33.87$, but the interaction was not significant ($F < 1$).

The right-hand panel of Figure 1 shows, for every session of the experiment, the group mean percentages of correct choices. Although the performance of the four groups was quite similar by the end of the experiment, during the initial sessions the two groups trained in the black-and-white arenas made more correct choices than did their counterparts trained in the white arenas. In addition, the performance of the group trained in the black-and-white rectangle was superior to that of the group trained in the black-and-white kite. In support of these observations, a Kruskal–Wallis ANOVA of individual mean percentages of correct choices for the 14 sessions combined revealed a significant difference among the groups, $H(3) = 15.38$. Subsequent tests revealed that the mean percentages of correct choices were significantly higher for the black-and-white-rectangle group than for any other group, Mann–Whitney $U(10, 10) < 18$, and that the difference between the black-and-white-kite and the white-kite groups was significant, $U(10, 10) = 20.0$.

The histograms in the left-hand panel of Figure 2 show the mean percentage of time spent in the correct and incorrect search zones by the two groups tested in the kite. In keeping with the findings reported by Graham et al. (2006), the group trained in the black-and-white kite showed a stronger preference for searching in the correct than in the incorrect zone than did the group trained in the white kite. The results from the test trial with the groups trained in the rectangle can be seen in the right-hand panel of Figure 2. On this occasion, the discrimination between the two zones was more

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marked in the group trained in the white arena than in the group trained in the black-and-white arena. A three-way ANOVA of the individual times spent in the two search zones revealed a significant three-way interaction between the shape of arena, the color of walls during training, and search zone, $F(1, 36) = 6.45$. Subsequent tests of simple main effects revealed that the groups trained in the black-and-white kite and in the white rectangle expressed a significant preference for the correct over the incorrect search zones, $F_s(1, 36) > 11.77$, but this was not the case for the remaining two groups, $F_s(1, 36) < 2.43$. The test of simple main effects also revealed a significant interaction between the color of the walls and search zone in the kite, $F(1, 36) = 5.13$, but not in the rectangle, $F(1, 36) = 1.76$. The remaining findings from the three-way ANOVA were as follows: The effects of shape, color, and zone were all significant, $F_s(1, 36) > 4.96$. The Shape × Color interaction was significant, $F(1, 36) = 5.07$, but the remaining interactions were not significant ($F_s < 1$).

**Discussion**

Graham et al. (2006) demonstrated that a discrimination between two right-angled corners in a kite-shaped pool is facilitated...
if the color of the walls creating one corner is different than the color of the walls creating the opposite corner. The results from Experiment 1 replicated this effect and show that it does not occur in a rectangle. The initial concern of this discussion is to consider why learning based on geometric cues should be potentiated by the color of the walls in some shapes, but not in others.

One factor that may determine whether a cue is eligible for potentiation is its salience. Bouton, Dunlap, and Swartzentruber (1987) have shown, for example, that potentiation of flavor conditioning is more likely to occur if the target flavor is of low rather than high salience. During the test trial of the present experiment the white-kite group showed a poor discrimination between the correct and incorrect corners of the test arena, which indicates that the geometric cues on which this discrimination was based were of low salience. The white-rectangle group, in contrast, showed a good discrimination between the correct and incorrect corners on the test trial, which implies that the salience of the geometric cues for this group was relatively high. Perhaps, therefore, this difference between the salience of the geometric cues in the two arenas was responsible for the potentiation that was observed in the kite but not in the rectangle. An implication of this analysis is that subjects relied on one cue provided by the shape of the environment to discriminate between the correct and incorrect corners of the rectangle and a different cue to discriminate between the corresponding corners in the kite. Pearce et al. (2004) suggested that rats might find a goal that is hidden in one corner of a rectangle by searching for a long wall and then swimming to a particular end. This strategy, which would always lead the rat to a correct corner, would not be effective in a kite where it would take the subject either to the correct corner or to the apex. Instead, in the kite subjects might look for the corner where a short wall is to the left of a long wall, or they may learn to head in a particular direction with reference to a unique feature, such as the apex of the arena. If the foregoing analysis of potentiation is correct, then it follows that a long wall in a rectangle is of relatively greater salience than either of the two cues identified for the kite.

Whatever the merits of these proposals, the fact that the color of the walls potentiated learning based on geometric cues in the kite poses a problem for the claim that such learning takes place in a dedicated module that is impervious to nongeometric information. If this were the case, then the performance of the two groups trained in the kite should have been similar on the test trial. At the same time, the results from these two groups provide no succor to those theories of learning that assume that cues must compete for the control they acquire over behavior. The problem posed by potentiation for theories of learning has been appreciated for a number of years, and different ways in which this problem might be resolved have already been discussed extensively (Bouton et al., 1987; Rescorla, 1981; Rescorla & Durlach, 1981). For now, it may be sufficient to note that the present results, together with those reported by Graham et al. (2006), serve to demonstrate that the phenomena and principles of Pavlovian conditioning may also extend to spatial learning based on geometric cues.

The right-hand panel of Figure 2 shows that making the correct corner of the rectangle white and the incorrect corner black resulted in a poorer discrimination between these corners than when all four walls were white. Such a finding is important because it is only the second occasion on which learning based on the shape of the environment has been found to be restricted by the presence of nongeometric cues (see also Gray et al., 2005). However, neither the present result nor that reported by Gray et al. provides a particularly compelling demonstration of cue competition. The black-and-white-rectangle group was trained in a black-and-white arena and tested in one that was entirely white, which makes it possible that the relatively poor performance on the test trial was due to a generalization decrement brought about by the change to the arena. Similarly, in the study by Gray et al., it is conceivable that subjects trained with food in the corner by the single blue wall paid particular attention to this wall, so that its removal would again weaken responding through generalization decrement. The present results might also be criticized because, even though the discrimination between the two search zones was statistically significant in the black-and-white but not the white rectangle, the important interaction between the color of the walls and search zone was not significant. Notwithstanding these shortcomings, the results from the two groups trained in the rectangle imply that the shape of a rectangular pool may have to compete with the color of its walls for control over searching for a hidden goal. The purpose of the three remaining experiments was to explore this possibility further.

**Experiment 2**

An experimental group was trained to find a submerged platform in one corner of a rectangular swimming pool with two long walls that were black and two short walls that were white. Thus, the platform could be found by referring to the shape of the pool or to the color of the walls, and referring to either of these cues would lead the rat either to the hidden platform or to the diagonally opposite corner. To find out if the color of the walls affected learning based on the shape of the pool, the experiment ended with a test trial in a rectangle with four white walls.

A control–white (W) group was included in the study. This group was trained and tested in a rectangular pool with four white walls. The performance of this group on the test trial should indicate the control that can be acquired by pool shape over searching for the platform when pool shape is not influenced by manipulations involving the color of the walls. If the experimental group should show a poorer discrimination between the correct and incorrect corners of the rectangle than the control–W group, it would imply that learning based on the shape of the pool in the former group had been restricted by using walls of different colors. An alternative explanation for such an outcome is that the change to the arena for the test trial with the experimental group weakened the discrimination through a generalization decrement. To test this possibility a control–black-and-white (BW) group was treated in the same way as the experimental group, except that the color of the walls varied from trial to trial: On some occasions the long walls were white and the short walls were black, and on other occasions the opposite relationship was in effect. This group was therefore forced to rely on geometric information provided by the shape of the pool to find the platform. It also experienced a similar change to the pool for the test trial as did the experimental group, so that any difference between the test results for these two groups would be difficult to interpret in terms of generalization decrement.

Before describing the experiments, some comment is needed concerning two differences between the method of this experiment...
and that of Experiment 1. First, a beacon was not attached to the platform in the present experiment because we have generally found that training in a rectangle does not result in subjects heading for the incorrect corners as often as they do in a kite. Second, because all the groups were trained in an arena of the same shape, we used our conventional method of measuring the amount of time they spent in quadrants of the pool rather than in search zones (e.g., Pearce et al., 2004).

Method

Subjects and apparatus. The subjects were 30 naive, male hooded Lister rats (*Rattus norvegicus*) from the same stock and housed in the same manner as in the previous experiment. Subjects were assigned to the three groups in equal numbers. The apparatus was the same as in Experiment 1 except that the beacon was not used and the light-tight boxes for holding the rats between trials were placed on the floor in a corner of the test room.

Procedure. All rats received 17 sessions of training in a rectangular arena constructed from boards of the same dimensions as those used for the previous study. There were four trials in a session. The platform was located in the corners where a short wall was to the left of a long wall for half the rats in each group and in the other two corners for the remaining rats. The arena was constructed from two long walls that were black and two short walls that were white for the experimental group and from four walls that were white for the control–W group. The arena for the control–BW group was made from either short black and long white walls or long black and short white walls. Each configuration was used twice in every session in a randomly determined sequence. The first three trials of Session 18 were conducted in the same manner as were the preceding sessions. All rats then received a test trial in a rectangular pool constructed from four white walls. Each rat was released from the center of the pool and allowed to swim for 60 s in the absence of the platform. Procedural details that have been omitted were the same as for Experiment 1, except that rats were allowed to swim in the pool for 90 s before being guided to the platform.

The latency to escape from the pool was recorded on every trial. A record was also made of whether a rat entered a geometrically correct or incorrect corner after being released into the pool. For the purposes of analyzing the results from the test trial, the arena was divided into four, by lines that bisected it both horizontally and vertically, creating two correct quadrants and two incorrect quadrants.

Results

The left-hand panel of Figure 3 shows the group mean escape latencies for every session. Throughout the experiment, the escape latencies were shorter for the experimental group than for the other two groups. A one-way ANOVA of individual mean escape latencies for the 18 sessions combined revealed a significant difference among the groups, $F(2, 27) = 15.50$. Subsequent comparisons using the Newman–Keuls procedure confirmed that the escape latencies were significantly shorter for the experimental group than for either of the control groups and that the difference between the control groups was not significant.

The right-hand panel of Figure 3 shows, for every session, the group mean percentages of correct choices. The three groups developed a strong tendency to head directly for the correct corner as training progressed, but, with the exception of the final few sessions, this tendency was stronger in the experimental than in the control groups. To compare the performance of the three groups, we calculated individual mean percentages of trials on which a correct choice was made for the 18 sessions combined. Analyses of these results revealed a significant difference among the groups, Kruskal–Wallis $H(2) = 15.80$. Paired comparisons then revealed that there was a significant difference between the results for the experimental group and either the control–W group, $U(10, 10) = 12.5$, or the control–BW group, $U(10, 10) = 0.0$. The difference between the results from the two control groups was not significant, $U(10, 10) = 36.5$.

The results from the test trial, which can be seen in Figure 4, revealed that the experimental group spent approximately half of the test trial in the correct quadrants. In contrast, both control groups expressed a clear preference for the correct than the incorrect quadrants. A one-way ANOVA of individual mean percentages of time spent in the correct quadrant indicated that the
difference among the groups was significant, $F(2, 27) = 8.34$. Subsequent comparisons between pairs of groups, using the Newman–Keuls procedure, revealed a significant difference between the results for the experimental group and those for each of the control groups. The difference between the two control groups was not significant.

We also analyzed the results using one-sample $t$ tests to determine if the percentage of time spent in the correct quadrants by each of the three groups was significantly greater than would be expected on the basis of chance. These tests revealed that significantly more than 30 s of the test trial was spent in the correct quadrant of the pool by the control–W and control–BW groups, $t(9) = 6.96$ and 3.74, respectively, but not by the experimental group, $t(9) = 1.20$.

Throughout the training stage of the experiment, a record was made of the percentage of trials on which subjects headed directly for the corner containing the platform or for the diagonally opposite corner. If subjects were able to perceive the platform directly, then they should have headed for the corner containing the platform on the majority of trials. The 30 rats headed directly for the corner with the platform on 38.3% of all training trials, whereas they headed directly for the opposite corner on 40.7% of the trials. This difference was not statistically significant, $T(30) = 174.5$, and indicates that subjects did not use cues emanating from the platform itself to escape from the pool.

**Discussion**

The results indicate that the experimental group made less use of the shape of the test arena when searching for the platform during the test trial than did either control group. The difference between the results from the experimental and control–BW groups is particularly important because it implies that the poor performance of the experimental group was not entirely due to a generalization decrement brought about by the change to the apparatus for the test trial. Instead, the results from the experimental group imply that the presence of color as a cue for finding the platform during the training trials overshadowed the control acquired by the shape of the pool. On the basis of this finding, it would seem that the principles governing learning about the shape of the environment as a cue for finding a goal may not differ from those that govern learning about other cues. We conducted the next experiment to determine if this conclusion is also true when a blocking rather than an overshadowing design is used.

**Experiment 3**

A plan of the apparatus for the experiment, which was conducted with two groups and in two stages, is shown in Figure 5. During the first stage, both groups were trained to find a submerged platform that was located in one corner of a square pool with two black walls (thick lines) and two white walls (thin lines). The groups were then trained in a rectangular pool with black and white walls arranged in the same manner as for the first stage. The platform for the blocking group was located in the same corner with respect to the black and white walls as for the first stage, whereas for the control group it was located in the diagonally opposite corner. Thus, from the outset of Stage 2 the blocking group could find the platform by relying on the cues they had used previously, and there would be no need for this group to refer to cues provided by the shape of the pool. If the shape of the pool is in competition with the color of the walls for control over searching for the platform, then the Stage 1 training should result in the blocking group learning rather little about the location of the platform relative to the shape of the pool. To test this prediction, subjects were placed in a rectangular pool with four black walls where the only information to guide their behavior was provided by the shape of the pool.

On the other hand, if the control group were to refer in Stage 2 to the cues that were used in Stage 1, then the group would be led to a corner with no platform. This group might then learn about the significance of the shape of the pool for finding the platform during Stage 2, and on the test trial the group should show a stronger preference for the correct over the incorrect corner than would the experimental group.

During the test, the control group spent slightly more time in the correct quadrant than did the experimental group, but this difference was not statistically significant. The absence of a significant difference between the groups may have occurred because learning about the shape of the pool had not reached asymptote in the control group. Additional training was therefore given to both groups.
groups in the rectangle before a second test trial was conducted. In the experiments by Graham et al. (2006), the color of the walls of the arena occasionally influenced the outcome of a test trial. In view of this possibility, half the rats for the second test were placed in a rectangle with four black walls and half were placed in a pool with four white walls.

Method

Subjects and apparatus. The subjects were 24 male rats from the same stock and housed in the same conditions as for Experiment 1.

The apparatus was the same as for Experiment 2 except that additional acrylic panels were used to create a square pool for the first stage of training. This pool was built from four boards which were 1.41 m long but otherwise constructed in the same manner as the walls of the pool used in Experiment 1. Two of the walls were black, and two of the walls were white. The walls were arranged to create one corner with two black walls and an opposite corner with two white walls. The rectangular pool used in the second stage of the experiment was constructed from a short black wall to the left of a long black wall, with the remaining walls being white.

Procedure. Stage 1 consisted of 14 sessions in which both groups were required to escape from the square pool by swimming to a submerged platform in one corner. The platform was located in the corner where the black wall was to the left of the white wall for half the rats in each group and in the opposite corner for the remaining rats. The orientation of the square pool was changed from trial to trial in the same manner as for the rectangular pool in Experiment 1. Throughout this stage of the experiment, a record was made of the number of trials in each session on which rats swam directly to the correct corner without first entering another corner.

The 22 sessions of Stage 2 of the experiment took place in the rectangular pool, where subjects were again expected to escape by swimming to a submerged platform that was located in one corner. The arrangement of the black and white walls for the corner containing the platform was the same as for the training in the square for the experimental group and the opposite of this arrangement for the control group. Rats were guided to the platform if they failed to find it within 60 s. On every trial in the rectangular arena, a record was made of which corner the rat entered first. For the purposes of discussion, the correct corner is defined as the one containing the platform, the corner diagonally opposite this corner is referred to as the opposite corner, the corner that is closest to the correct corner is referred to as the near corner, and the remaining corner is referred to as the far corner.

There were four trials in every session except Sessions 15 and 22 of Stage 2, which contained three training trials and a 60-s test trial with the platform removed from the pool. The first of these test trials was conducted in a rectangular pool with four black walls. The second was conducted in a rectangular pool with four white walls for half the rats in each group and with four black walls for the remaining rats. A record was made for both test trials of the amount of time spent by each rat in the quadrants of the pool containing the corners that were geometrically equivalent to the corner where the platform had been located. Procedural details that have been omitted from any stage of the experiment were the same as for Experiment 1.

Results and Discussion

Figure 6 shows the mean escape latencies for the two groups for every session of the experiment. The most salient feature of these results is the considerably longer escape latencies for the control than for the experimental group at the outset of training in the rectangle (Session 15 onward). To compare the performance of the groups, we calculated individual mean escape latencies for the 14 sessions in the square pool, for the 15 sessions before the first test trial, and for the 7 sessions before the second test trial. The differences between the two groups were significant for the second of these periods, \( t(22) = 4.83 \), but not for the first or third, \( t(22) < 1.01 \).

The left-hand panel of Figure 7 shows the mean percentage of trials on which subjects headed directly for the corner containing the platform for each session of training in the square arena. The performance of both groups improved as training progressed, and a comparison of individual mean percentages of correct first choices, for the 14 sessions combined, failed to reveal a statistically significant difference between the groups, \( U(12, 12) = 44.0 \).

The central panel of Figure 7 shows the percentage of trials in each session on which the experimental group headed directly for each of the four corners of the rectangular pool without first entering another corner in the second stage of the experiment. Throughout this stage, the experimental group headed directly for the correct corner on the majority of trials. There was also a slight tendency to head directly for the far corner more frequently than for the near or opposite corners. The right-hand panel of Figure 7 shows the equivalent results for the control group. Because of its prior training, this group showed a stronger tendency to swim first to the opposite than to the correct corner, but this preference was soon reversed. For the 15 sessions before the first test trial, the mean percentage of trials on which subjects headed directly for the correct corner was significantly greater for the experimental than for the control group, \( U(12, 12) = 19.5 \). A similar analysis for the remaining sessions revealed that the difference between the groups was not significant, \( U(12, 12) = 70.0 \).

The mean percentages of time spent in the correct quadrants of the rectangular pool by the two groups during the first and second test trials are shown, respectively, in the left- and right-hand panels of Figure 8. In the first test trial, the control group spent slightly more time in the correct quadrant of the pool than did the experimental group, but this difference was more marked in the second test. A comparison of individual percentages of time spent in the correct quadrants of the pool revealed no difference between the groups during the first test trial, \( t(22) = 0.79 \). In contrast to the first
test, which was conducted in a pool with four black walls for all rats, the second test was conducted in a pool with four black walls for 6 subjects in each group and in a pool with four white walls for the remaining subjects. Those rats in the experimental group that were tested in a black arena spent 50.3% of the trial in the correct quadrant, whereas those tested in a white arena spent 52.9% of the trial in the correct quadrant. The equivalent results for the control group were, respectively, 59.3% and 65.8%. A two-way ANOVA with the factors of group and color of the test arena revealed a significant effect of group, $F(1, 20) = 10.70$, but the effect of color of the arena, $F(1, 20) = 1.84$, and the interaction were not significant.

One-sample tests revealed that significantly more than 50% of the second test trial was spent in the correct quadrant by the control group, $t(11) = 4.89$, but not by the experimental group, $t(11) = 0.84$.

With sufficient training in the second stage of the experiment, the control group showed a clear preference for searching in the correct rather than the incorrect quadrants of the pool. A similar preference was not observed in the experimental group. The implication of these findings is that the original training in the square enabled the color of the walls to block learning about the shape of the rectangular pool in the experimental group in the manner envisaged by theories of associative learning (e.g., Rescorla & Wagner, 1972).

There is, however, an alternative explanation for the outcome of the experiment that needs to be considered. At least during the initial sessions of Stage 2, the control group spent more time in the pool and made more errors of visiting an incorrect corner than did the experimental group. It is thus conceivable that this extra exposure to the pool provided the control group with more opportunity than the experimental group to learn about the position of the platform with reference to geometric cues. One objection to this explanation is that there was no difference between the results from the two groups during the first test trial, after a period of training when they experienced different amounts of exposure to the pool, but there was a difference between their results during the second test trial, after a period of training when the amount of exposure to the pool for the two groups was similar. If the amount of exposure to the pool during the training trials determined the

![Figure 7](image1.png)

**Figure 7.** The mean percentages of trials on which a correct choice was made by both groups during the 14 sessions of training in the square pool (left-hand panel) and on which each of the four corners was entered first by the experimental group (center panel) or the control group (right-hand panel) during the 22 sessions of training in the rectangular pool in Experiment 3.

![Figure 8](image2.png)

**Figure 8.** The mean percentages of time spent by the two groups in the correct quadrants of the rectangular pool during the first (left-hand panel) and the second (right-hand panel) test trials of Experiment 3.
outcome of the test trials, then it is not clear why the final stage of training resulted in the two groups behaving differently on the second test trial but not the first. A related objection to this explanation for the outcome of the present experiment has its roots in Experiment 1. Throughout most of the training sessions in that experiment, the two groups trained in a black-and-white arena made more correct choices than the two groups trained in an arena with four white walls. The groups trained in the black-and-white arena therefore received less varied exposure to the training environment than did those trained in the white arena, and on the basis of the account under consideration, the former groups should have made less use of the geometric cues than the latter groups. Although this prediction was confirmed for the groups trained in the rectangle, the opposite outcome was found for those trained in the kite. These results show, therefore, that making errors of heading directly toward an incorrect corner does not determine the extent to which geometric cues are used to indicate the location of the platform.

Experiment 4

In the previous experiment, the platform was always located in a corner created by walls of different colors. One purpose of the present experiment was to test the generality of the results from Experiment 3 by examining whether blocking also occurs when the two walls creating the correct corner are the same color. An experimental group was trained initially to find an escape platform in a square pool with two adjacent walls that were black and two adjacent walls that were white and with the platform located in one of these corners. The group was then trained in a rectangle in which the color of the walls was the same as in the square and with the platform located in a corner of the same color as for the previous stage. If the results from the Experiment 3 are reliable, then during a final test trial in a rectangular arena with walls of uniform color, the experimental group will fail to show a preference for the geometrically correct corners.

There were two control groups. A control-opposite group received similar treatment to the experimental group, except that the platform was located in a corner with walls of one color in the square and walls of opposite color in the rectangle. This group was expected to head for the corner opposite to the one housing the platform at the outset of the training in the rectangle. A control-random group was trained in the square with the platform located randomly from trial to trial in each of the four corners. This group was not expected to express a preference for any corner when it was introduced to the rectangle. Despite these differences between the groups, if theories of cue competition (e.g., Rescorla & Wagner, 1972) apply to the spatial domain, then both groups should learn about the significance of cues provided by the shape of rectangular pool for finding the platform and show a clear tendency to head for the correct corners on the test trial.

To help rats in the control-random group find the platform in the square pool, a landmark was suspended above it on every trial. The same landmark was shown to the other two groups, but the corner it occupied was selected at random and thus did not indicate where the platform could be found.

Method

Subjects and apparatus. The subjects were 36 male, naive rats from the same stock and housed in the same conditions as those used for Experiment 1. The apparatus was the same as for Experiment 2, with the addition of a landmark that consisted of a black foam ball that was 10 cm in diameter and was attached to a clear acrylic rod that was clamped horizontally to the top of one wall of the square arena so that the center of the ball was located 25 cm from a corner on a line that bisected the corner. The lowest point of the ball was 28 cm above the surface of the pool.

Procedure. The first 14 sessions of the experiment were conducted in the square pool, which was constructed from two adjacent black walls and two adjacent white walls. The platform was located in the corner created by two black walls for half the rats in the experimental and the control-opposite groups and in the corner created by two white walls for the remaining rats in these groups. The landmark, which was attached to the apparatus for both groups, occupied a different, randomly selected corner of the square pool on each trial, with the constraint that it was located above the platform once in every session. The landmark was also attached to the square pool in the manner just described for the control-random group, with the platform directly beneath it on every trial.

The next 11 sessions were conducted in the rectangular pool constructed from two adjacent black walls and two adjacent white walls. The relationship between the color of the walls and the shape of the pool remained constant for all the training trials. The landmark was not used in this phase of the experiment. For the experimental group, the platform was located in the corner of the same color as for the training in the square pool, whereas for the control-opposite group the platform was located in the corner that was opposite in color to that where it was located in the square pool. The platform was located in the black corner for a randomly selected half of the rats in the control-random group and in the white corner for the remaining rats. There were four training trials in the first 10 sessions of this stage and three in the 11th session. The final trial of the 11th session was conducted in an arena with four black walls for those rats who were required to swim to the black corner in the rectangular pool and four white walls for the remaining rats. Subjects were placed in the pool for 60 s in the absence of the platform. The remaining procedural details were the same as for the previous experiment.

Results and Discussion

The left half of Figure 9 shows the mean escape latencies for three groups for each of the sessions of training in the square pool, and the right half shows the equivalent results for the training in the rectangular pool. A one-way ANOVA of individual mean escape latencies for the 14 sessions combined for the training in the square pool failed to reveal a significant difference among the groups \( F < 1 \), but a similar ANOVA revealed a difference among the groups during the training in the rectangular pool, \( F(2, 33) = 55.38 \). Newman–Keuls comparisons indicated that the escape latencies were significantly shorter for the experimental group than for either of the two other groups, and the latencies for the control-random group were significantly shorter than for the control-opposite group.

From left-hand panel of Figure 10, it is evident that the control-random group persistently made fewer correct choices on being released into the square pool during the first stage of the experiment than did the other two groups, but all three showed a marked improvement in the frequency with which they headed directly for the correct corner as training progressed. Analysis of individual mean percentages of correct choices for the 14 sessions combined revealed a significant difference among the groups, \( H(2) = 6.56. \)
Subsequent comparisons between pairs of groups revealed that the control-opposite group made significantly more correct first choices than did the control-random group, $U(12, 12) = 28.0$, but neither of the two remaining comparisons was significant, $U_{s}(12, 12) = 28.0$.

The mean percentages of trials on which the experimental, the control-opposite, and the control-random groups headed directly for the four corners of the rectangular pool during the second stage of the experiment are shown, respectively, in the second, third, and fourth panels from the left of Figure 10. At the outset of this stage, the control-opposite group made very few correct choices after being released into the rectangular pool and the control-random group made an intermediate number of correct choices, whereas the experimental group’s performance was similar to that at the end of training in the square pool. An analysis of individual mean percentages of correct choices for the 10 sessions combined revealed a significant difference among the groups, $H(2) = 22.15$. Subsequent comparisons then revealed that each group differed significantly from the other two groups, $U_{s}(12, 12) = 26.0$. By the end of the experiment, the groups were making very few errors of heading directly for an incorrect rather than the correct corner.

The results from the test trial can be seen in Figure 11, which shows for each group the mean percentage of time that was spent in the correct quadrants of the rectangular pool. The experimental group spent less time in these quadrants than did either control group. For those subjects in the experimental group that were tested in the black arena, the mean percentage of the trial that was spent in the correct quadrant was 50.2, whereas for those tested in the white arena the mean percentage was 54.7. The equivalent results for the control-opposite group were 64.2% in the black arena and 69.1% in the white arena; for the control random group, 60.1% in the black arena and 65.7% in the white arena. A two-way ANOVA of individual percentages of time spent in the correct quadrants revealed a significant effect of group, $F(2, 30) = 12.79$, but the effect of arena color just failed to reach the conventional level of significance, $F(1, 30) = 4.06$, and the interaction was not significant ($F < 1$). Subsequent comparisons, using the Newman–Keuls procedure, revealed that the percentage of time spent in the correct quadrants by the experimental group was significantly less than that spent by either the control-opposite or the control-random group. The difference between the two control groups was not statistically significant. One-sample tests revealed that each of the control groups spent significantly more time in the correct than in the incorrect quadrants on the test trial, $t_{s}(11) = 5.85$, but this was not the case for the experimental group, $t_{11} = 1.24$.

The results from the experimental and the control-opposite groups replicate the findings from Experiment 3 and extend their generality in two ways. On the one hand, it appears that blocking does not depend on the use of a particular combination of walls in the corner containing the platform. On the other hand, it appears that a demonstration of blocking does not depend on the use of a control condition that encourages rats to head for an incorrect corner at the outset of Stage 2.

Figure 9. The mean escape latencies for every training session by the three groups of Experiment 4. (The left half shows the mean escape latencies for training sessions in the square pool, and the right half shows those for the training sessions in the rectangular pool.)

Figure 10. The mean percentages of trials in Experiment 4 on which a correct choice was made by the three groups during the 14 sessions of training in the square pool (left-hand panel), and on which each corner of the rectangular pool was selected first by the experimental group (second from the left), the control-opposite group (second from the right), or the control-random group (right-hand panel) during the subsequent 11 sessions.
General Discussion

In four experiments, we examined how learning about the position of a goal relative to the shape of a rectangular pool is affected when the color of the walls provides additional information about where the goal can be found. The findings from Experiment 1 indicate that the color of the walls may overshadow learning about the shape of the pool, and Experiment 2 provided additional support for this conclusion. The remaining experiments demonstrate that it is possible for prior training with colored walls in a square arena to block learning based on the shape of the walls in a rectangular arena. These experiments thus demonstrate for the first time with mammals that learning about the position of a hidden goal relative to geometric cues provided by the shape of the environment can be impaired by the presence of other cues. The results from Experiment 1 also reveal that learning about the position of a goal with reference to the shape of a kite can be potentiated if the walls adjacent to the goal are of a different color than the more distant walls. This finding replicates results reported by Graham et al. (2006). The implications of discovering potentiation in a kite-shaped pool are considered in some detail by Graham et al., and to a lesser extent in the discussion to Experiment 1, and there is little to be gained by repeating here what has already been said. Instead, the main purpose of the following section is to examine why learning based on geometric cues is impaired by the presence of some cues, but not others.

A number of experiments have shown that learning about the position of a goal relative to the shape of the environment is unaffected by the presence of a nearby landmark when the goal is hidden in one corner of a rectangular arena. These failures of cue competition have been reported with a different feature in each corner of the rectangle (Kelly et al., 1998), with a distinctive feature in the corner where the goal was located (Wall et al., 2004), with a rod attached to the goal (Pearce et al., 2001), and with a landmark near to the goal but on its far side relative to the corner (Hayward et al., 2004). In all of these experiments, therefore, the goal could be found by searching for a landmark that was relatively small compared with the size of the arena. Studies of Pavlovian conditioning have revealed that the extent to which one stimulus will overshadow (Kamin, 1969a; Mackintosh, 1976) or block (Hall, Mackintosh, Goodall & Martello, 1977) another is governed by their relative salience. Thus, the failure to find blocking and overshadowing in the studies just mentioned might have occurred because the salience of the landmark was less than that of the shape of the environment. The overshadowing and blocking that was seen in Experiments 2, 3, and 4 can then be explained if it is accepted that the salience of the color of the walls was equal to or greater than the salience of the cues provided by the shape of the rectangle.

The idea that the relative salience of cues determines whether spatial learning based on the shape of the environment will be overshadowed is attractive, but it may not be correct. Hayward et al. (2004) trained two groups of rats to find a submerged platform in a rectangular pool by referring either to the shape of the pool or to a landmark near the platform. The landmark was found to be the more effective cue. In another experiment, Hayward et al. found that the same landmark did not overshadow learning based on the shape of the same pool. The implication of this finding is that overshadowing failed to occur even though the landmark was more salient than the shape of the pool. Having acknowledged this finding, it seems likely that the color of the walls of the arenas used in the present experiments was a particularly salient cue, and it might be a mistake to rule out completely the possibility that the salience of a cue plays an important role in determining whether it will restrict learning based on the shape of the environment.

If the presence of one cue is to restrict what is learned about another cue, then they must both be attended to at the same time. It is conceivable that this condition was not met in those studies where a landmark failed to influence learning based on the shape of the environment. For instance, to find a hidden goal, a rat might rely exclusively on a landmark that is near it; however, once the goal has been reached it might then attend to other cues, such as the shape of the pool, to confirm where the goal is located. Alternatively, an animal might attend to different stimuli on different trials, so that learning about the significance of a landmark near a goal on one trial would not influence learning related to the shape of the environment on another trial. In the case of the present experiments, however, because the cues relating to shape and color were both provided by the walls of the pool, it seems unlikely that subjects attended to one and ignored the other, either while they were swimming to the platform or once they had reached it. Perhaps it was for this reason, therefore, that the present experiments were more successful than previous studies at revealing blocking and overshadowing with the shape of the environment.

Another reason for the failures to observe a competition between the shape of the environment and landmarks within it can be based on the fact that the latter are normally located near the goal. It is thus conceivable that when an animal is released into an arena with a distinctive shape, especially if it is some distance from the goal, it may then fail at first to detect the landmark. The subject might therefore use the shape of the arena as an aid to finding the landmark and learn nothing about the position of the goal relative to the shape of the arena (which might be blocked or overshadowed by the landmark). During a test trial in the absence of the landmark and goal, subjects might still head for the correct region of the arena, and thereby fail to show overshadowing or blocking because they were searching for the landmark rather than the goal.
This explanation is less likely to apply to the present studies because the diffuse nature of the color cues would make them just as effective as the shape of the pool for finding the platform, no matter where the subject was located.

Despite the different findings they have revealed, the experiments by Graham et al. (2006) and the present experiments point to at least one common conclusion: Learning about the shape of the pool does not progress independently of the color of its walls. This conclusion contradicts the claims by Cheng (1986) and Gallistel (1990) that learning about the shape of the environment takes place in a dedicated geometric module that is impervious to other stimuli. Gallistel (p. 208) included among these other stimuli the luminance characteristics of the objects that form the shape. On this basis, using the color of the walls to indicate the location of the platform should not have restricted learning about the shape of the pool in the present experiments, or augmented it in the studies by Graham et al. Cheng and Newcombe (2005) raised the possibility that memory for the shape of the environment may incorporate information about the properties of the objects creating the shape. They did not, however, offer any rules for specifying how learning based on one set of cues will influence learning based on the other, which makes it difficult to judge the significance of the present findings for their proposal.

The results from the final three experiments, and from the groups trained in a rectangle in Experiment 1, are compatible with the idea that cues compete for the control they acquire over behavior. The Rescorla–Wagner (1972) theory assumes that stimuli are in competition for the associative strength they acquire, but they may be in competition for some other limited resource, such as the attention they are paid. Thus, it is possible that the white-rectangle group of Experiment 1 and the experimental group of Experiment 2 failed to discriminate between the correct and incorrect corners of the rectangle on the test trial because they paid so much attention to the color of the rectangle during training that they failed to notice its shape. Blocking might have occurred in Experiments 3 and 4 for the same reason. It is not easy to refute these explanations, but one may question whether it is reasonable to suppose that animals failed to notice the shape of the pool when they were attending to the color of the walls that create the shape. In addition, the results from the groups trained in the kite in Experiment 1, as well as those from Graham et al. (2006), make it difficult to accept that rats do not attend to the shape of the pool when the color of the walls indicates where the platform can be found.

If it is accepted that the present results show that the cues of color and shape are in competition with each other, it becomes necessary to specify how animals represent the shape of the environment. Cheng (1986; see also Cheng & Gallistel, 2005; Gallistel, 1990) has proposed that when they are placed in an environment, animals then represent in one form or another its overall shape. There is, however, a growing body of experimental evidence showing that animals navigate with reference to local rather than global geometric features created by the shape of their environment (Esber, McGregor, Good, Hayward, & Pearce, 2005; McGregor, Jones, Good, & Pearce, in press; Pearce, Good, Jones, & McGregor, 2004; Tommasi & Polli, 2004). For example, Pearce et al. have argued that to escape from a rectangular pool rats look for, say, a long wall and then swim to the appropriate end. Thus, the findings from the present experiments may well have been a consequence of a competition between the color of the walls and a component of the shape they created rather than of the overall shape.

The four reported experiments have shown for the first time with mammals that the presence of a cue can restrict learning about the significance of the shape of the environment for finding a hidden goal. This finding stands in contrast to a body of evidence that shows that learning about the shape of the environment is unaffected by the presence of nongeometric cues. It also stands in contrast to the claims that have been made concerning the impenetrability of a geometric module. The theoretical challenge now is to understand why on some occasions learning based on the shape of the environment is unaffected by the presence of other cues and on other occasions it is either promoted or disrupted.

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