How does a yak find a drink?

Do animals use cognitive maps? **John M. Pearce** *investigates.*

MOST animals must navigate through their environment in order to reach a desirable location, such as a place that has provided food, water or shelter. Although it has been argued that this ability may depend upon sophisticated intellectual processes, my research has shown that animals rely on relatively simple strategies for finding their way. Moreover, these strategies occasionally lead animals to simple solutions for problems that pose considerable difficulty to humans.

Cognitive maps

The photograph shows a herd of yaks near a lake in the Himalayas. If this were the only supply of water, then a yak foraging in this bleak environment might find itself some distance from the lake when it was thirsty. How would the yak know in which direction to head in order to reach the lake?

Back in 1948, Tolman proposed that animals solve this problem by referring to a cognitive map, which can be likened to an aerial photograph of the environment they inhabit. To find water, the yak would have to identify its position on the map, and then use the map to plot a course to the lake. A wide range of experiments have been conducted to test whether animals possess cognitive maps, but many of their findings have been controversial or difficult to interpret. However, in 1986, Ken Cheng, a PhD student then working at the University of Pennsylvania, conducted a study whose findings led many to believe that rats do indeed navigate by using something similar to a cognitive map.

Rats were placed in a rectangular chamber containing a variety of landmarks and were required to find food that was consistently hidden in one corner. Cheng found during a test in the absence of food and the landmarks that rats would search predominantly in either the correct corner of the chamber or in the corner that was diagonally opposite. These results led him to conclude that during their training rats remembered the shape of the rectangular chamber, and identified the position of food relative to this shape. In other words, the rats could be said to have acquired a very simple cognitive map.

Cheng's results and theoretical proposals have had a considerable impact. His findings have been replicated with species ranging from goldfish to humans. Researchers have generally accepted his theoretical conclusions and agree that the capacity to form a map based on the shape of the environment is widespread, an evolutionarily ancient trait, and a fundamental cognitive mechanism (e.g. Sovrano *et al*., 2002).

An alternative explanation

A moment's reflection reveals that Cheng's results do not necessarily demonstrate that the rats identified the position of food with reference to the overall shape of the

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rectangular environment. Figure 1a shows a rectangular arena, with a goal (the black circle) hidden in one corner. Instead of referring to the shape of the arena, rats could find the goal by looking for a corner with certain properties: for example, a corner where a long wall was to the left of a short wall. Alternatively, they may have simply looked for a wall of a particular length, a long wall, say, and then headed for the corner at its right-hand end. If rats could be shown to adopt either of these strategies, then the claim that they use map-like information to find a hidden goal would be undermined. An experiment was therefore conducted in our laboratory in order to identify the strategy rats adopt when searching for a hidden goal in a rectangular environment (Pearce *et al.*, 2004).

Rats were placed in a rectangular swimming pool (1.8 m x 0.9 m) and were required to escape from it by finding a platform. The task was not physically demanding because rats are good swimmers and are known to have travelled over 400m in open water. Several steps were taken to ensure the rats found the platform with information provided only by the shape of the pool. To prevent cues outside the pool from serving as landmarks, the pool was surrounded by a curtain and the orientation of the rectangle was changed from trial to trial. To prevent rats from seeing the platform, it was submerged just below the surface of the water which was made opaque by the addition of a white dye. After several training trials a clear pattern of behaviour emerged. Upon being released, the rats would either swim directly to the corner containing the platform; or they would swim to the diagonally opposite corner, where they would spend a few moments before swimming across the pool to the platform.

To identify the strategy that was used to find the platform, a test trial was conducted in a kite-shaped pool (see Figure 1b). The walls of the rectangle were used to construct the kite, and the corners where a short wall met a long wall were both right-angled. We recorded the corner that rats headed for directly after being released into the pool. The numbers in Figure 1b show the percentage of trials on which the group headed directly for each of the four corners of the kite. It is clear that they preferred to swim directly to the apex (Corner A), or to Corner B, rather than the other corners.

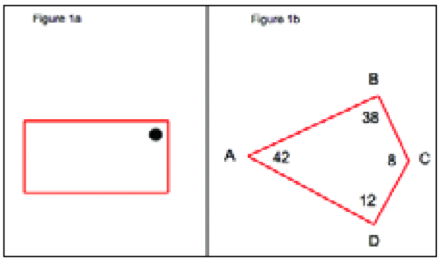

Figure 1a. Plan of the rectangular arena used by Cheng (1986) and Pearce *et al.* (2004). Figure 1b. Plan of the kite-shaped arena used by Pearce *et al.* (2004).

The first conclusion to draw from this finding is that it lends no support to the idea that rats found the platform in the rectangle by referring to the overall shape of the pool. If they had adopted this strategy then, because of the lack of congruence between the two shapes, the rats should be lost in the kite and therefore show no preference for one right-angled corner over the other. The results, on the other hand, are entirely in keeping with the suggestion that the rats found the platform in the rectangular arena by searching for a long wall and heading for its right-hand end. On the majority of trials rats headed directly for the corners that were at the right-hand end of the long walls A–D and A–B.

Why did rats opt to navigate with reference to the long wall, when they could also have used the short wall to find the platform in the rectangle? If they had learned to swim in a particular direction relative to the short wall, then the test trial would have revealed a different outcome. We suspect the answer to this question is that animals are disposed to pay more attention to, and hence learn more readily about, salient rather than weak stimuli. The long wall may well have gained control over our rats' behaviour because it was more salient than the short one.

Understanding spatial relations

An important aspect of spatial behaviour in humans is our ability to recognise the relationship between two objects. For instance, if a goal is located near to landmarks A and B, then we might learn to head in a direction that ensured A was to the left of B. Another objective of my research has been to determine whether animals can detect spatial relationships of this sort. In fact, the results from the above experiment imply that animals may have difficulty with appreciating this type of spatial information. When they were in the rectangle they had the opportunity to learn that the platform was located in a corner where a long wall was to the left of a short wall. If they had adopted this strategy then when placed in the kite they should have headed directly for Corner B, and shown little interest in the other corners. The fact that they headed equally often for Corner A and Corner B implies that the rats did not find the platform by referring to the spatial relationship between the long and short walls.

An experiment that I conducted some time ago lends further support to the conclusion that animals find it difficult to learn about the significance of spatial relationships (Pearce, 1991). However, rather than investigate such relationships as 'to the left of', the experiment examined whether pigeons could use information based on the relative size of two objects that were shown on a small television screen behind a response key. On half the trials a pattern similar to the two in the top row of Figure 2a (see over) was shown and signalled food. On other trials a pattern similar to the two in the bottom row of the figure was shown and signalled no food. A wide variety of patterns were used with each of the two vertical bars varying in height from near the bottom to near the top of the television screen. Thus the birds had to learn that food was available when the two bars were of the same height, but not when they were of a different height. Despite many sessions of training, the birds failed completely with this task. Moreover, manipulating the manner in which the experiment was conducted in a variety of ways consistently failed to reveal any indication of the birds solving the problem. In keeping with the results from the first experiment, therefore, it appears that animals find it very difficult to respond on the basis of a spatial relationship between two objects.

To confirm that it was indeed the task of identifying the relationship between the bars that posed such a challenge to the birds, rather than some other aspect of the experimental design, a further experiment was conducted. Pigeons were trained with a discrimination involving the patterns shown in Figure 2b. The patterns were composed of three vertical bars that each varied in height. Patterns whose average height was somewhat lower than the mid-point of the television screen signalled food (top panel of Figure 2b), whereas patterns whose average height was somewhat greater than the midpoint of the screen signalled no food (lower panel of Figure 2b). On this occasion, the birds were required to focus on an absolute property of each pattern – its average height, or the area that it occupied – rather than on any relationship between the components that made up the pattern. This difference turned out to be critically important because the pigeons now solved the problem with little difficulty, and soon came to respond more rapidly during patterns belonging to the short rather than the tall category.

Mental snapshots

To explain this successful discrimination, I have argued that pigeons take a mental snapshot of each pattern and remember its significance (see Haselgrove *et al*., 2005). When they are confronted with a new 'short' pattern, it will be similar to previous patterns from this category that have signalled food, and through stimulus generalisation the birds will respond to it rapidly. Likewise, when they see a new 'tall' pattern, its similarity to previous tall patterns will result in the birds responding slowly (Pearce, 1994).

The same account will not work for the discrimination shown in Figure 2a. An inspection of the two right-hand panels of the figure should make it evident that despite belonging to different categories, the two patterns are physically similar because there is rather little difference between the vertical bars in terms of their height. Moreover, this will be true for many pairs of patterns from the opposing categories. In the absence of any ability to tell the difference between these pairs on the basis of the spatial relationship between the bars, there will be considerable generalisation between them and the discrimination will be difficult to solve.

Each year I present these two problems to my undergraduate students for a practical class. Rather than signalling food, the patterns are followed by the presence or absence of a tone. The students invariably find the first problem trivially simple, and are soon able to predict which patterns will be followed by a tone. The second problem, however, poses a much greater challenge, with many of the students never finding the solution. I suspect that this pattern of results is a consequence of Cardiff undergraduates having a much greater ability and willingness to learn about the significance of spatial relationships than pigeons. They easily solve the first problem with the rule 'same height means a tone, different height means no tone'. When confronted with the second problem they might also search for a relational solution such as 'centre bar shorter than the right bar means a tone', which will of course lead them down numerous blind alleys.

If pigeons are unable to learn about the significance of spatial relationships then they would not adopt this misleading strategy for the second problem, and thus solve it by referring to the only information available to them – the absolute property of the height of the patterns, or their area. In contrast, as shown earlier, referring just to the physical properties of the patterns would be of no value for the first problem where the solution depends upon the ability to appreciate spatial relationships.

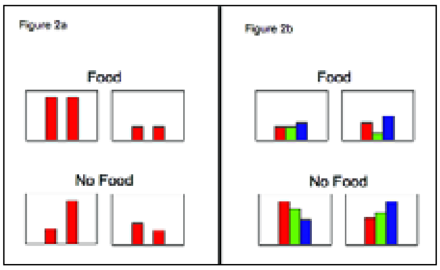

Figure 2. Examples of the patterns that signalled food (top row) or no food (lower row) in experiments in which the relationship between (a) the heights of the two bars and (b) the average heights of the three bars indicated the trial outcome.

Back to the yak

Premack (1983) has argued that an ability to understand relationships, including spatial relationships, depends upon a capacity for abstract or symbolic thought. By failing to reveal any evidence that animals refer to the spatial relationship between two objects, either to find a hidden goal or to solve a discrimination, my experiments imply that they are incapable of representing abstract information. If this conclusion is correct, then it is perhaps not surprising that we have also been unable to find any evidence that animals navigate by means of cognitive maps. By their very nature, maps encode information about the spatial relationships between objects. It is hard to see how an animal could construct or use a cognitive map if it lacked the symbolic code necessary to appreciate these relationships.

The implication of this conclusion for the yaks in the photograph is that they would not locate the lake by referring to a cognitive map. They would also be unable to locate the lake by referring to the relationship between two or more landmarks, for instance by searching for the scree slope to the left of the high mountain. They would, instead, identify the position of the lake with reference to its direction and distance from a prominent landmark. Provided a yak could see the landmark, it should then be able to find the lake.

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DISCUSS AND DEBATE

To what extent does animal intelligence depend upon abstract thought?

Do the conclusions drawn from experiments with rats and pigeons apply to other species?

Can experiments in the laboratory help us understand behaviour in more naturalistic settings?

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