

## **Preexposure effects in spatial learning: from gestaltic to associative and attentional cognitive maps**

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In this paper a series of studies and theoretical proposals about how preexposure to environmental cues affects subsequent spatial learning are reviewed. Traditionally, spatial learning had been thought to depend on gestaltic non-associative processes, and well established phenomena such as *latent learning* or *instantaneous transfer* have been taken to provide evidence for this sort of cognitive mapping. However, reviewing the literature examining these effects reveals that there is no need to advocate for gestaltic processes since standard associative learning theory provides an adequate framework for accounting for navigation skills. Recent studies reveal that attentional processes play a role in spatial learning. The need for an integrated attentional and associative approach to explain spatial learning is discussed.

Animals such as rats, mice, cats, chimpanzees and even human beings, readily learn to locate an invisible goal by reference to landmarks that lie at varying distances from it by using a cognitive map encoding information about the relationship between the goal and the landmarks. Learning about cognitive maps had been thought to depend on non-associative processes. Traditional cognitive map theories assume that spatial learning involves the building of a complete representation of the environment in an all-or-none manner, in response to novelty and independently of reinforcement. According to that view, the cognitive map is thought to be a highly flexible representation of space that automatically updates whenever novel information appears in a known environment. Organisms capable of building up and using such cognitive maps may acquire information about their environment by mere exposure to it independent of reinforcement. Once a map of the spatial relationships between cues within the environment has been established it may be possible for organisms to make novel short-cuts between two points even

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through unexplored areas of the environment (e.g., Morris, 1981; O'Keefe & Nadel, 1978; Tolman, 1948).

More recent approaches provide fundamentally different definitions of cognitive maps to that envisaged mainly by O'Keefe and Nadel (1978). Gallistel's definition of the cognitive map involves any record in the central nervous system of macroscopic geometric relations among surfaces in the environment used to plan movements through the environment (1993, 1994). For Gallistel the central issue concerns the type of geometric relations a map encodes. There are no restrictions on how animals might learn about space. A cognitive map is how space is represented in the animals' brain, and there is no need to advocate a gestaltic approach over an associative process as the basis for building up such representations.

Conditions for spatial learning have been widely studied during the last few years, and there is growing evidence pointing to the involvement of associative processes in spatial learning. Chamizo (in this issue) reviews evidence that cue competition effects, blocking and overshadowing, occur in spatial learning—just as in Pavlovian conditioning. Such effects are now widely regarded as a hallmark of associative learning.

The possibility that spatial learning might be associative in nature would compel us to review some well established preexposure phenomena such as latent learning or instantaneous transfer, which have been taken as evidence for the use of non-associative gestaltic cognitive maps. According to traditional cognitive map theories (e.g., Nadel, 1992; O'Keefe & Nadel, 1978), preexposure to a given environment could be expected to benefit subsequent performance in locale learning as an accurate map will have already been established.

In the associative learning literature, on the other hand, exposure to a situation may either retard or facilitate acquisition depending on certain factors. It is well established that non-reinforced exposure to a stimulus that is to serve as a conditioned stimulus in a Pavlovian paradigm typically retards subsequent learning—that is, it leads to latent inhibition (Lubow, 1989). Latent inhibition is often attributed to a decline in the salience or associability of the stimulus produced by preexposure (e.g., McLaren & Mackintosh, 2000). However, non-reinforced exposure to two or more stimuli typically enhances subsequent discriminative learning, thus resulting in perceptual learning (for a full review see Hall, 1991). This perceptual learning effect has been suggested to depend on a simple associative mechanism: preexposure to two or more stimuli reduces the salience or associability of their common elements, thus increasing their discriminability (McLaren & Mackintosh, 2000). An alternative view on preexposure effects in the associative learning literature takes into account an attentional mechanism. During preexposure, animals may learn to ignore stimuli that are irrelevant for predicting reinforcement whereas they learn to attend to those that are perceived as good predictors for reinforcement (e.g., Mackintosh, 1975; Sutherland and Mackintosh, 1971).

Early studies on preexposure effects in spatial tasks demonstrated that learning to locate a new goal in a familiar environment was easier than in a novel one. However, recent research provides strong evidence that sometimes learning to locate a goal in a familiar environment is harder than in a novel one. Traditional cognitive map theory cannot account for disruption of learning after exposure to the spatial cues. Standard associative and attentional theories can account for both the facilitation and disruption of learning after preexposure. The aim of the present paper is to review these studies on preexposure and to assess if the results can be explained by a simple associative learning mechanism.

### **FROM GESTALTIC TO ASSOCIATIVE COGNITIVE MAPS: LATENT LEARNING AND INSTANTANEOUS TRANSFER**

#### **Latent learning: Do animals acquire useful information for navigation by being exposed to the environment?**

A classic procedure for investigating the effects of prior exposure on subsequent spatial learning is the latent learning task first reported by Blodgett (1929; see also Tolman & Honzik, 1930). The first studies of latent learning were originally designed to test the law of effect, that is to say whether reinforcement and active exploration of the environment were necessary for learning a maze task. Theoretical background for these experiments implied that solving a maze task by means of associative processes should involve learning S-R associations (Hull, 1943) whereas learning in the absence of reward or an animals' performance would imply a different sign-Gestalt strategy—the building up of a cognitive map (Tolman, 1932, 1948).

In his pioneering study, Blodgett (1929) trained two groups of rats in a six-unit alley maze in such a way that each rat was put into the maze once a day and allowed to freely move around from the start to a goal box where it could find some food. One group was run in orthodox fashion, receiving food at the end of the maze in each training trial. The other group was given six non-reinforced trials—preexposure to the maze—and received food in the goal box only from the seventh day of the experiment onwards. A rat's performance was analysed in terms of the number of errors (defined as entrances in blind alleys) during the nine days of the experiment. Rats that were fed at the end of the maze throughout the experiment, gradually learned to avoid blind alleys and achieved the learning asymptote on the seventh day of training. More interesting, preexposed rats showed only a slight reduction in number of errors during the first seven days of the experiment. However, after being fed in the goal box on the seventh trial, these rats showed a rapid reduction of errors in trials eight and nine. After one single rewarded trial, the rats achieved a level of performance the rats with no preexposure took seven days of rewarded training to reach. Tolman stated that, "during the non-rewarded trials these (preexposed) animals had been learning much more than they had exhibited" (Tolman, 1948, p. 194).

This latent learning experiment is still often taken as evidence for learning in the absence of reinforcement, thus demonstrating the use of gestaltic cognitive maps by rats. However, there are at least two reasons why it is difficult to accept this conclusion. First, as Mackintosh (1974) pointed out, it is fruitless to deny the absence of reinforcement during the preexposure stage of the experiment. Either removal from the goal box, or the aversiveness of entering and having to turn round in narrow blind alleys, might be sufficient to strengthen true-path responses, thus favouring Hull's S-R analysis of maze performance in the rats. Second, associative learning is known to involve the establishment of other associations as well as S-R associations. It is well established that S-S, R-S or even hierarchical S-(R-S) associations develop between different stimuli, responses and outcomes in standard conditioning tasks (e.g., Adams & Dickinson, 1981; Rescorla, 1990). Thus, excluding the possibility of rats learning a S-R association does not mean that they are learning in a non-associative way.

Henry Gleitman (reported in Tolman, 1949) provides us with an experiment that would help to see how associative structures other than S-R connections could be involved in learning spatial tasks presumably based on gestaltic cognitive maps. Gleitman used a T-maze and trained hungry rats to get equal amounts of food at two distinctive goal boxes located at each end of the maze (the goal boxes were not themselves visible from the choice point). In a subsequent phase, the goal boxes were located in a different room and the rats were put into each of them. Rats were given a shock in one of the goal boxes and merely exposed to the other one. When returned to the maze, rats were given a test trial in which they were allowed a choice between the two arms of the maze leading to each of these goal boxes. Almost 90% of the rats avoided at the choice point the arm leading to the goal box in which they had been shocked. Obviously, there is no way in which rats could learn to avoid the goal box associated with shock at the choice point of the T-maze during the second phase of the experiment through a S-R association. However, associative theory could account for this result by assuming that rats learnt about the cues in the choice point of the T-maze and the goal boxes through S-S associations, as well as about the goal boxes and the differential outcome experienced during the second stage of the experiment. Integration of this knowledge is well documented in sensory preconditioning experiments (e.g., Rizley & Rescorla, 1972), and is easily accommodated by contemporary associative learning theories.

The latent learning experiments reviewed above involve animals exploring a maze in such a way that they can learn something useful for finding their way towards a goal. Other experiments investigating latent learning address the degree to which this knowledge can be acquired independently of the behaviour of the organism. Traditional cognitive map theories propose that knowledge about spatial relationships between objects and places in an environment is represented in a form that is independent of behaviour (Morris, 1981; O'Keefe & Nadel, 1978; Tolman, 1948). An associative approach would predict that as an animal gains experience with cues that are useful in arriving at a correct solution to a problem its

performance will improve. These cues would include both a subset of surrounding cues as they are viewed from a goal as well as subsets of the cues generated by the animals' movements around the environment. Training would allow the relations between these cues to be strengthened, thus improving use of the cues to guide navigation (Whishaw, 1991).

Several studies have addressed this issue over the years; some of them have been widely taken as evidence for traditional cognitive mapping theories whereas others have been taken to demonstrate the involvement of associative processes in spatial learning. The most basic situation in which one could test if active exploration of the environment is a requisite for good spatial performance is the one suggested by Thorndike (1946), consisting of running rats through a maze in a kind of trolley car, and later testing what they had learned.

McNamara, Long and Wike (1956) attempted to closely follow Thorndike's suggestion in a spatial discrimination learning experiment using a T-maze (see also Dodwell and Bessant, 1960, for a rather similar demonstration of latent learning using a water maze with eight choice points). A group of rats was trained to find food at the end of one of the arms of the maze whereas a further group of animals were given the same experience but were conducted to the goal in a basket. Performance in the discrimination task was then tested in an extinction test in which all the animals were allowed to run the T maze and choose between the two arms. The authors found that animals in the "basket" group, that were not allowed to move through the maze during the training stage of the experiment, performed as well as those in the "run" group, that were allowed to freely move around the maze.

The study reported by McNamara et al. (1956) constitutes a simple demonstration of how rats can learn about space without actively exploring the experimental environment. Other experiments have been reported using more complex procedures and subjects other than rats. For example, Menzel (1973) conducted a series of experiments with chimpanzees in which he tested their memory and knowledge of a familiar large environment (an outdoor enclosure 30.5 by 122 m) by hiding food in various places. In this test, a chimp was carried along by the experimenter and shown where the food was hidden in eighteen different locations. After this, the observer chimp was released into the area along with several other control subjects, chimps who had not had the opportunity to observe the food being hidden. This test was then repeated three more times on successive days, using different hiding places inside the experimental environment in each test trial. The animal that had been shown the food hiding places found a mean of 12.5 pieces of food per trial, whereas the control subjects found a mean of 0.21 pieces of food. Also, the observer chimp followed a very precise route in which it ran unerringly from one hiding place to the next, rarely visiting each hiding place more than once.

The experiments by McNamara and Menzel clearly demonstrate latent learning without performance in both novel and familiar environments. In these experiments rats and chimps were carried around the experimental environment and so they had the opportunity to experience the subset of

spatial cues generated by the movements of the experimenter who carried the chimp or the basket where the animal was sitting. A question that arises is whether animals would be capable of acquiring knowledge about the environment from a single location, without any movement at all. Perhaps a better demonstration of latent learning without performance is that reported by Keith and McVety (1988) using rats as subjects in a Morris swimming pool navigation task.

In the swimming pool task (Morris, 1981), rats are placed in a circular pool of water in which they must swim until they find a submerged platform standing somewhere in the pool. Although the rats are unable to see the platform itself, they readily learn to navigate to it from a variety of starting locations, by learning the location of the platform in relation to distal cues surrounding the pool. Keith and McVety (1988) trained several groups of rats in a swimming pool located in a given environment for several sessions until they mastered the procedural requirements of the task. Then, latent learning was tested in a different swimming pool located in a novel environment—a different experimental room. Some rats were allowed to see the new environment from the submerged platform before the first swimming trial. A second group of rats were only allowed to see the room cues from a position located in the opposite quadrant to where the platform would be found during the test trial. Finally, some rats were not allowed to see the environment before swimming. The results of the test trial showed that rats that were allowed to see the room cues from the platform location performed better—spent less time in finding the platform—than rats that only viewed the room cues from the wrong location. These rats, in turn, performed better than those that had received no exposure to the novel environment prior to the test trial. Keith and McVety concluded that rats were able to navigate accurately on the first trial after viewing the novel room from the hidden platform. According to the authors of this study, “these findings underscore the fact that the knowledge system subserving place learning can acquire and store spatial information independently of the actions that the animal must use to navigate to its goal” (Keith & McVety, 1988, p. 150). This view is consistent with traditional cognitive map theories (Morris, 1981; O’Keefe & Nadel, 1978; Tolman, 1948).

However, no matter how clear and convincing this argument is, it does not eliminate the possibility of an associative explanation. In a review of Keith & McVety’s findings, Chew Sutherland & Whishaw (1989) pointed out that the improved performance these authors observed after preexposure fell far short of the accurate performance one could expect if the knowledge system subserving place learning was really independent of animals’ behaviour. Of course, rats can acquire useful information from the experience of being placed in the platform: rats become familiar with the subset of surrounding cues as they are viewed from the goal. However, fully accurate performance is only achieved when rats have been allowed to swim through the pool, that is to say, when they become familiar with the subsets of the cues generated by the animals’ movements around the environment. Spatial learning would consist

in the establishment of associations between the subset of cues viewed from the goal and the different subsets generated by the rats' movements.

In a series of experiments, Whishaw (1991) reported evidence favouring this associative view. Whishaw replicated the basic finding originally reported by Keith and McVety, in which preexposed rats showed improved performance when compared with non-preexposed rats. However, when spatial performance of rats passively preexposed was compared with a group of rats that were given a single swimming trial before the test, Whishaw found that the latter perform more accurately than the former animals. Also, placement on the platform combined with a swim resulted in the best performance. These results strongly suggest that rats use associative rather than gestaltic learning processes to solve spatial tasks.

**Instantaneous transfer: Do animals plan and execute short cuts through unknown areas of known environments?**

If, as O'Keefe and Nadel (1978) suggested, animals use a cognitive map to navigate, then they should be able to plan and execute a novel short cut to a given goal within that space. Evidence for such instantaneous transfer of spatial information to novel positions was presented by Morris (1981) using the Morris water maze. Rats were trained to locate a submerged platform, being started from set locations. Once the escape latencies were consistently short the animals were released from a novel start position. If the rats were using a flexible cognitive map developed during training then they should be able to use the map to locate the platform from a novel start point, taking a path they had never followed before. If the rats, on the other hand, located the platform using a more limited associative process, then the subset of cues around the novel start position would not have been one with which the rats had associated the position of the platform. The rats should, therefore, have difficulty locating the platform from a novel release position.

Morris found that the rats quickly located the platform from a novel release point and stated that the demonstration of instantaneous transfer was evidence that the rats formed and utilised a cognitive map of the distal landmarks around the pool. Further studies (Keith & McVety, 1988; Sutherland & Dyk, 1984; Sutherland & Linggard, 1982) also found evidence for instantaneous transfer in rats in the water maze. However, other studies (Alyan, 1994; Benhamou, 1996; Chew et al., 1989; Hamilton, Driscoll and Sutherland, 2001; Sutherland, Chew, Baker & Linggard, 1987; Whishaw, 1991) found that various types of animals had difficulty in locating the platform from a novel position if they had not had an opportunity to explore the entire pool. Sutherland et al. (1987) re-examined Morris' and Sutherland's own previous results and pointed out that although by the final trial of training the rats were swimming in a direct line from the release point to the submerged platform, this was not the case for the initial training trials. During the initial trials the rats would search the entire pool and were able to approach the platform from any angle. Thus the rats may well have been able to associate any subset of distal cues with the position of the platform. The

authors argued that rats must be completely restricted from being able to view the cues from the novel start position if one is to claim that they are using a mapping strategy rather than associative memory to locate the platform.

Sutherland et al. (1987) set out to meet this criterion by placing a barrier in the water maze during training. The barrier could be lowered into the pool, bisecting it and restricting access to only one side of the pool. Sutherland et al. (1987) found that the rats which had been restricted to one side of the pool during training, and thus unable to view the distal cues from the test release point, were slower to find the platform in the test trial than the rats which had had unlimited access to the whole of the pool during training. A further group which were placed in the opposite side of the pool but restricted from swimming back to the platform also showed poor escape latencies on the test trial. It would appear that viewing the cues from the novel release point without being able to associate them with finding the platform meant the rats were unable to utilise the cues in the test trial. Sutherland et al. (1987) concluded that there was little evidence for instantaneous transfer of spatial information to the novel start position and so little evidence for the theory that the rats formed a cognitive map. In order for the rats to navigate directly from the novel release point to the submerged platform the rats must have been able to view the distal cues from the novel release point and been able to swim from this point to the platform during training. Such requirements would fit with the theory that the rats were using an associative process rather than a mapping strategy to locate the platform.

Further evidence for the use of associative mechanisms rather than cognitive maps came from Alyan's (1994) studies of instantaneous transfer. Alyan placed mice in the centre of a circular arena and required them to locate their home nest at the periphery of the arena. Only mice which had had 24 hrs to freely explore the arena were able to locate the goal accurately using only the spatial cues around the arena. Mice which had been only able to view the cues from the den or from an adjacent arena for 24 hrs were unable to locate the den when tested. Alyan emphasised the importance of controlling for path integration (see Rodrigo, in this issue) when testing navigating with distal cues because she had previously noticed that passively transporting the mice allowed them to home accurately when tested. Overall Alyan concluded from her data that there was no evidence for instantaneous transfer. Thus, the encoding of distal cues in relation to finding a goal is more likely to be due to an associative process than to gestaltic cognitive mapping.

Hamilton et al. (2001) provided further evidence questioning the formation of cognitive map, this time in humans. They repeated Sutherland et al. (1987) findings testing human participants in a virtual water maze. Hamilton et al. restricted the access of the participants to one side of the pool and found that on test they were slower to locate the platform from a novel position on the other side of the pool than participants which had free access to explore all areas of the pool. Allowing the participants to view the distal cues from the novel start position without being able to return to the platform was not sufficient to improve test escape latencies. It seemed once again that only by associating the view of the distal cues from the release point with

locating the platform could the distal cues be used in the test stage. These results would suggest an associative memory rather a cognitive map was also used by humans to navigate in a virtual space.

An alternative suggestion for the findings of Sutherland et al. (1987) was put forward by Matthews and Best (1997). They also repeated Sutherland et al. (1987) experiments and found similar findings, that restricting the rats' access to part of the pool resulted in poor instantaneous transfer when the rats were released from a novel position. However, Matthews and Best suggested that the findings rather than casting doubts on the rat's ability to utilise a mapping strategy were a result of stimulus generalisation decrement in the test stage. They argued that in the test stage the removal of the barrier separating the two halves of the pool would have changed the appearance of the water maze to such an extent that it would not be surprising that there was a drop in performance. To illustrate the disruptive effect of changing the shape of the water maze between training and test trials, one group of rats was allowed access to all of the water maze during training. On the test trial a barrier was placed in the pool which did not bar the rats' direct swim path from the novel start position to the platform, but did change the shape of the pool. The rats showed increased escape latencies compared to rats where the barrier was not added on test, and similar escape latencies to those where the barrier had been removed on the test trial.

Matthews and Best's study included a fourth group which were also denied access to the part of the pool in which novel release point lay by a barrier in the pool. Initially the barrier split the pool down the middle, however over training it was gradually reduced in size and pushed back until by the final days of training it was only blocking access to the 5% of the pool which contained the novel start point. On test the barrier was not removed but moved around the pool so that the rats could be released from the novel start point but any stimulus generalisation could be reduced to a minimum. The rats performed as well as the rats with full access to the pool during training. As the rats had never had access to the novel release point until test the authors argued that the results support the finding of instantaneous transfer of spatial information.

The Matthews and Best's results do illustrate the detrimental effects of changing the shape of the pool between training and test. However, it must be questioned whether blocking the rats' access to a mere 5% of the pool would rule out the use of an associative solution. How different would the views of the distal cues be from just in front of the barrier from the views at the novel start point? The rats during training would have been able to associate the views in front of the barrier with finding the platform as they were able to return from this point to the platform over the final days of training. Matthews and Best state that rats in this "phased group" were found not to swim to the barrier in the final days of training but it is difficult to rule this explanation out completely. Overall the evidence for instantaneous transfer of spatial information is weak and the results suggest that in this situation both non-human animals and humans use associative processes rather than true gestaltic mapping strategies with which to navigate.

### **A SIMPLE ASSOCIATIVE MECHANISM**

Modern associative learning theory is based on the assumption that learning can be adequately described by specifying the strengths of associations between events (or their features) and the error-correcting rules governing changes of associative strength (e.g., Mackintosh, 1975; McLaren & Mackintosh, 2000; Pearce & Hall, 1980; Rescorla & Wagner, 1972). More important, this approach recognises no distinction between the types of stimuli that can enter into associations and supposes that all types of stimulus relationships can be encoded associatively. According to that view, preexposure to spatial stimuli should affect their associability in a similar way to other stimuli—like tones and lights—routinely employed as conditioned or discriminative stimuli in standard classical and instrumental conditioning tasks.

As we have already argued in the Introduction, preexposure produces latent inhibition in standard Pavlovian conditioning. The same result is often observed after preexposure when the subjects are required to learn to discriminate between two distinctive stimuli. However, when the subjects face a harder discriminative task, that is when they have to learn a discrimination between two similar stimuli sharing many features in common, preexposure facilitates subsequent learning—a perceptual learning effect—due to the differential loss of associability between the common and the unique features of the stimuli (McLaren & Mackintosh, 2000).

According to traditional cognitive map theories, prior exposure to the spatial cues can only be expected to benefit subsequent performance in spatial tasks, by ensuring that an accurate map has already been established. In the spatial domain, preexposure to spatial cues has been widely demonstrated to facilitate subsequent learning, and that facilitation has been often taken as evidence for non-associative cognitive map acquisition. On the other hand, an associative theory of spatial learning predicts that preexposure should result in latent inhibition—loss of associability—of the preexposed stimuli. This latent inhibition could either retard or facilitate subsequent learning depending on the difficulty of the spatial discrimination the subjects are required to learn.

Chamizo & Mackintosh (1989), using rats as subjects, assessed the effect of preexposure on learning a discrimination task in a Y-maze in which the two goal arms were distinguished both by the nature of their flooring (sandpaper versus rubber) and the colour of their walls (white versus black). During preexposure, the animals experienced both goal arms but one at a time, an arrangement of doors preventing access to other parts of the maze. A control group received equivalent treatment except that for them the maze-arm presented during preexposure was always covered with an irrelevant plastic flooring and had unpainted walls. During test, rats in preexposed group showed a slower rate of acquisition of the discrimination task than control animals. This result constitutes a simple demonstration that preexposure can sometimes retard subsequent spatial learning, and was interpreted by Chamizo and Mackintosh as an instance of latent inhibition. More interesting, when the

distinctive walls of the arms were substituted by identical unpainted walls, thus increasing the proportion of common elements to the two arms, the reversed effect was found, that is preexposure facilitated subsequent learning of the task (Chamizo & Mackintosh, 1989; Trobalon, Chamizo & Mackintosh, 1992). This result was interpreted as an instance of perceptual learning. Taken together these results seem to demonstrate that the likelihood of observing facilitated or retarded learning after preexposure in a spatial discrimination depends on the proportion of common elements the stimuli—goal arms—share, and suggest that the differential latent inhibition of common and unique elements of the stimuli to be discriminated plays a role in producing differential preexposure effects.

The original findings by Chamizo and Mackintosh (1989; see also Trobalon et al., 1992), demonstrated how preexposure to intra-maze cues (e.g., flooring and colour of walls) could either retard or facilitate subsequent spatial learning. However, one could object that learning about intra-maze cues could involve processes different to those involved in true spatial learning with distal cues located at a certain distance from the maze arm and the goal location. Trobalon, Sansa, Chamizo and Mackintosh (1991) addressed this issue by using distal extra-maze landmarks to define the location of reward in a maze whose arms were almost identical. These authors found that preexposure facilitated learning (a perceptual learning effect) when the animals were asked to solve a difficult discrimination—between two arms separated by  $45^\circ$ —whereas it produced retarded learning (a latent inhibition effect) when solving an easier discrimination task—between two arms separated by  $135^\circ$ .

Similar results have been obtained by using different strategies in a maze (Rodrigo, Chamizo, McLaren & Mackintosh, 1994; Sansa, Chamizo & Mackintosh, 1996). For example, Rodrigo et al. (1994) found that a preexposure treatment of placing rats on the arms that were to be used for the test trials (which were at  $90^\circ$  to each other) disrupted the acquisition of the subsequent discrimination. In contrast, if the rats were placed on arms that were intermediate between the arms that were used for the test stage, then subsequent learning was facilitated. To explain their findings, Rodrigo et al. pointed out that in the test phase, rats were required to discriminate between two different locations. According to the theory of McLaren and Mackintosh (2000), preexposure to the landmarks around the maze should reduce their associability. When preexposure was to the intermediate arm, loss of associability should affect the elements common to the two locations between which the animal had to discriminate, thus increasing their discriminability. However, when preexposure took place on the arms that will be used for test, loss of associability should affect the unique elements of each location, thus reducing their discriminability. Sansa et al. (1996) replicated those results employing a complementary strategy. Their maze was surrounded by a circular, black enclosure, with a total of only four landmarks to define the location of the various arms. For one group, these landmarks were situated at the end of the four arms of the maze; for another, they were placed halfway between each pair of arms. Spatial discrimination learning was retarded in the

group preexposed to landmarks situated at the end of each arm but facilitated in the group preexposed to landmarks that lay between arms.

Further evidence supporting this associative view has been obtained in rats learning to locate the submerged platform in the Morris swimming pool. Some evidence has been reported suggesting that learning to locate an invisible goal in a swimming pool requires at least two distal landmarks. Prados and Trobalon (1998; see also Rodrigo, Chamizo, McLaren & Mackintosh, 1997) found that rats trained to find a platform defined by four landmarks were able to search accurately for it in the presence of any configuration of at least two landmarks while the performance of the animals dropped to chance in the presence of a single landmark. This finding suggests rather strongly, as Whishaw (1991) argued, that rats do not use single landmarks to navigate toward a submerged platform, but rather configurations of two or more landmarks. If that is so, then the unique cues that rats use to identify the location of the platform are not individual characteristics of separate landmarks, but the configural cues generated by a view of two or more landmarks (Rescorla, 1972). We could suppose that, when learning to locate an invisible goal defined by a number of landmarks (e.g., A, B and C), animals have to discriminate between different configurations, let us say P (ABC), Q (AB) R (AC) and S (BC), where each of these configurations emerge from the view of two or more landmarks, but has nothing in common with either. If that is so, preexposure to configurations of at least two landmarks at a time would reduce the salience of their unique configural cues and thus generate a latent inhibition effect. This preexposure to configurations is not possible if animals only see one landmark at a time. Therefore, preexposure to individual landmarks is not expected to produce retarded learning in the swimming pool since preexposure to the landmarks in isolation would leave the salience of the configural cues untouched. On the other hand, since individual landmarks are precisely the common elements to the configurations rats use to navigate, preexposure to the landmarks in isolation should reduce their salience without affecting the salience of the configurations. Consequently, discriminability between the configurations is expected to be improved and, therefore, spatial learning facilitated.

This prediction has been supported by the results of an experiment reported by Prados, Chamizo and Mackintosh (1999; see also Prados, 2000), who preexposed rats to a set of four landmarks that surrounded the pool before training them to swim towards the invisible platform. Animals that were preexposed to combinations of two adjacent landmarks were slower in finding the platform than non-preexposed animals (a latent inhibition effect). On the other hand, rats preexposed to the landmarks individually—that is to say, one landmark at a time—showed a facilitated learning (a perceptual learning effect). It might be worth mentioning that this perceptual learning effect was only found when the discrimination task was rather complex—because the four landmarks used to define the platform location shared an explicit common element.

To conclude this section, we can say that standard associative learning theory provides an adequate framework for explaining preexposure effects in

the spatial domain by appealing to a simple associative mechanism: loss of associability of stimuli produced by preexposure.

### **PREEXPOSURE EFFECTS AND ATTENTION**

Another series of experiments offers a different explanation for the effects of preexposure on spatial learning from that of latent inhibition and perceptual learning (Pearce, Roberts, Redhead & Prados, 2000; Prados, Redhead & Pearce 1999; Redhead, Prados and Pearce, 2001). It has been suggested on several occasions that more attention will be paid to a stimulus which predicts a significant outcome (e.g., George & Pearce, 1999; Lawrence, 1949; Mackintosh, 1975; Sutherland & Mackintosh, 1971). In terms of the experiments in spatial learning discussed in the present paper, if a configuration of distal cues were consistently associated with the position of a goal then attention to the cues should increase.

Prados, Redhead & Pearce (1999) trained rats to swim to a visible platform in a water maze surrounded by a curtain. For the experimental group of rats, four distal cues were hung inside the curtain whereas for the control group there were no distal cues. In the test stage the distal cues were present for both groups and the rats were required to find a submerged platform in a new location using the distal cues to learn its position over a series of trials. The experimental group preexposed to the distal cues in training had significantly shorter escape latencies over the test trials than did the control group. Prados, Redhead and Pearce (1999) suggested that the improved performance of the experimental group was due to rats attending to the distal cues at the start of the test stage. The rats attended to the distal cues because the spatial relationship between the cues and the position of the visible platform during training had remained constant.

Alternative explanations for the effects of pre-exposure have been put forward throughout the paper including latent learning of a cognitive map (Keith & McVety, 1988) and a decrease in associability of common cues within a set of distal cues (McLaren, Kaye & Mackintosh, 1989; McLaren & Mackintosh, 2000). Both of these types of theories might explain Prados, Redhead and Pearce's initial findings. Any cognitive map constructed during preexposure might be quickly adapted to incorporate the position of the submerged platform in the test stage. Alternatively a decrease in the associability of common features of the distal cues during preexposure would lead to an increase in the ability of the experimental group to discriminate between the cues in the test stage. Both outcomes would make it easier for the group preexposed to the distal cues to learn the position of submerged platform. However, a subsequent experiment was more difficult for them to explain.

There were three groups, firstly, a group receiving the same treatment as the experimental group in the previous experiment, Group Stable-Same; secondly a group which received the same training stage as Group Stable-Same but in the test stage the configuration of surrounding distal cues was

changed, Group Stable-Diff; finally a group for which the configuration of distal cues was changed after each training trial, Group Mix. If preexposure to distal cues allowed the rats to form a cognitive map of the distal cues which could be later used to find the submerged platform, then only Group Stable-Same would benefit from their preexposure. If preexposure resulted in a decrease in associability of common features amongst the distal cues then all three groups would benefit from preexposure since, although the configurations of the cues were changed in groups Stable-Diff and Mix, the actual cues were the same in both training and test stages. Indeed since the configurations of distal cues changed between training and test trials for groups Stable-Diff and Mix, they should suffer no loss in associability of the configural cues. But there would be such a loss in Group Stable-Same where the configuration remained the same. As discussed, earlier research suggests rats use the configuration of two or more landmarks to locate a platform (Prados & Trobalon, 1998; Rodrigo et al., 1997). It might be expected then that Group Stable-Diff and Group Mix be better than Group Stable-Same.

Prados, Redhead and Pearce (1999) found that groups Stable-Same and Stable-Diff had shorter escape latencies over the series of test trials than Group Mix. This set of results fitted the idea that attention would be paid to distal cues which had a constant spatial relationship with the position of the platform goal. Although for Group Stable-Diff the configuration of cues changed between training and test, attention should have been paid to the cues at the start of testing because during training the rats could use the cues to locate the platform. The rats of Group Mix could not use the configuration of distal cues during training to locate the platform and so attention to the cues in this group declined.

The findings of the previous experiment suggest that preexposure to distal cues irrelevant to the position of the platform would result in a decline in attention to the cues and so poor subsequent spatial learning. Redhead et al. (2001) illustrated this decline in attention by comparing the results of a group of rats receiving the same training as Group Mix with a group receiving no preexposure. They found that the group preexposed to irrelevant distal cues produced longer escape latencies when they were required to locate a submerged platform than the group for which the cues were novel in the test stage.

Several findings discussed earlier in terms of a change in associability might equally be explained in terms of a change in attention to irrelevant cues. For example Prados, Chamizo & Mackintosh (1999) demonstrated that preexposure to adjacent pairs of distal cues from an array of four resulted in poor spatial learning when rats were required to learn the location of a submerged platform in the presence of all four cues. Prados, Chamizo and Mackintosh (1999) suggested the poor subsequent learning was due a reduction in the salience of the configural cues between the preexposed pair of cues. A drop in attention to irrelevant cues might equally explain the results. The rats were preexposed to the cues by being placed on a platform in the centre of the pool and allowed to see a 90° segment of the curtains around the pool. The rats would be exposed to cue A on the left of the segment and cue B

on the right. They then would be exposed to cues B and C, with cue B on the left and cue C on the right. This treatment ensured the rats viewed the cues in two different positions, which may have made them appear irrelevant to the position of the platform and so reducing attention to the cues.

One methodological difference between the studies of Prados, Chamizo and Mackintosh (1999) and Redhead et al. (2001) was that the rats observed the cues after being placed on the platform in the former study while the rats swam to a visible platform in the preexposure stage of the latter study. Such differences in procedure may have affected the results of the respective studies. Prados, Redhead and Pearce (1999) compared the effects of active and passive preexposure. They found that if during preexposure the platform remained in the same position during each session but was moved to a new location at the start of each new session active preexposure enhanced spatial learning. The result fitted the predictions of an increase in attention to the distal cues. Active preexposure required the rat to locate the platform and so emphasised the relevance of the distal cues to the platform's position within a session. Passive preexposure, however, had a detrimental effect on subsequent spatial learning. Sitting on a platform having been placed there might not be as rewarding as being on the platform after having had to swim to it. The passive preexposure effect, therefore might be due to latent inhibition of the distal cue. Alternatively, the fact that the platform did not move within a session might have been of little importance to a passively preexposed rat. Of more importance might have been that the distal cues were irrelevant to the position of the platform at the start of each session. However speculative the latter explanation, passive preexposure effects could be explained in terms of both an attentional process or a loss in associability.

Pearce et al. (2000) directly tested the predictions which would lead from either a change in attention or a loss of associability of the distal cues following passive preexposure. The rats were placed on the platform during preexposure trials. The platform remained in the same place throughout the preexposure stage. For one group, Group Stable, the positions of the cues remained fixed, for another, Group Unstable, the position of the cues was systematically changed throughout preexposure. For a third group, Group Control, there was no preexposure to the distal cues. A change in attention to relevant and irrelevant cues would result in improved spatial learning in Group Stable and poor spatial learning in Group Unstable in comparison to Group Control. However, a drop in salience of configural cues as predicted by McLaren and Mackintosh (2000) would result in better learning in Group Unstable than Group Control. The findings followed the predictions of a change in attention: Group Stable showed the best spatial learning over the test trials while Group Unstable showed the poorest.

The results of preexposure described in this section have been discussed in terms of a change in attention best described by Mackintosh's (1975) model. Other models of attention fair less well in terms of predicting the results. The Pearce-Hall (1980) model, for example, states that attention to a cue should decline as it becomes an accurate predictor of an outcome. It would incorrectly predict that preexposure to a configuration of cues which

has a stable relationship with the position of the platform would lead to a decline in attention to the cues and poor spatial learning whereas preexposure to an unstable configuration would lead to the opposite.

It should be noted that even Mackintosh's model does not exactly predict the results of the studies described in this section. When rats were trained to swim to the platform during preexposure they were trained to swim toward a beacon attached to the platform. This beacon was a more accurate predictor of the location of the platform as the position of the platform remained the same only across the four trials of a session. According to Mackintosh's theory therefore attention should have remained high for the beacon but declined even for the stable configuration of cues. The exact nature of the attentional process utilised in a spatial task requires further investigation. While the findings fit with the spirit of Mackintosh's model, developed within the typical associative paradigm of tones paired with food, they do not follow the model's predictions completely.

Attentional processes certainly appear to play a role in the effects of preexposure in spatial learning. However, simple changes in attention to relevant or irrelevant cues can not correctly predict all of the results discussed in the paper. For instance several studies demonstrated an enhancement of spatial learning following preexposure to cues placed between the arms of a maze while a disruption in performance following preexposure to cues over each arm (e.g., Rodrigo et al., 1994; Sansa et al., 1996). As both types of cue would have had a stable spatial relationship to the arms of the maze it would be impossible to explain the difference in terms of changes in attention to relevant or non relevant cues. As discussed in the previous section these findings can, however, be easily explained via means of a simple associative model described by McLaren and Mackintosh (2000). It would seem therefore, that there is a need for an integrated attentional and associative approach to fully explain the effects of preexposure on spatial learning.

## CONCLUSION

The stated aim of the present paper was to review the studies on preexposure in spatial learning and to assess if the results can be explained by a simple associative learning mechanism or whether they indicate the formation of a more complex gestaltic cognitive map. Initially demonstrations of latent learning and instantaneous transfer of spatial information (e.g., Keith & McVety, 1988; Morris, 1981) following preexposure to spatial cues were taken as evidence that animals could form and utilise cognitive maps. The ability to execute novel routes could not be achieved via an associative process and would require the formation of a map encoding the spatial relationship between the cues in the locale. However, subsequent experiments suggested that there was little evidence for these phenomena and that spatial learning may be governed by the rules of associative learning (Sutherland et al., 1987; Whishaw, 1991).

The remainder of the paper examined what processes might predict the effects of preexposure in spatial learning. The majority of the findings discussed could be accounted for by an elemental theory of associative learning (McLaren & Mackintosh, 2000). The model accounts for the effects of preexposure by predicting a loss in associability of stimuli. For example in Prados, Chamizo and Mackintosh (1999) preexposure to configurations of pairs of distal cues around a pool led to poor spatial learning due to a reduction in the associability of the configural cues required to define the location of the platform in the pool. Preexposure to individual cues, on the other hand, led to facilitation of spatial learning as the elements of the individual cues would lose in associability in comparison to the configurations which would remain the same making discrimination between the configurations easier.

Not all findings could be explained by a loss in associability, however, as Redhead et al. (2001) described how preexposure to a constantly changing configuration of four spatial cues retarded subsequent spatial learning. Such preexposure might be expected to reduce the associability of the individual cues while not reducing that of the configurations leading as before to facilitated learning. An alternative attentional explanation was put forward for these and further results demonstrating a facilitation of spatial learning following preexposure to a stable configuration of cues. In accordance with Mackintosh's (1975) model of attention, attention was said to be paid to a stable configuration of cues relevant to the position of the platform, while attention declines to an unstable configuration irrelevant to the platform's position.

From the studies reviewed it is not possible to choose between the attentional and the associative model as neither can predict all the results described. It may be more acceptable to state that some preexposure effects are due to a reduction in associability of the cues and their common elements and some effects are due to a change in attention to the spatial cues owing to their relevance to solving the spatial discrimination. Further research needs to be done to clarify the relationship between the associative and attentional processes involved in spatial learning.

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