THE UNIVERSITY OF HULL

Cue competition between shapes in human spatial learning

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by

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ABSTRACT

In many species, including humans the basic ability to move to a goal is essential to survival. Central to understanding how this ability operates in the cognitive systems of humans and other animals is whether learning about spatial relationships follows the same principles as learning about other kinds of contingent relationships between events. In non-spatial contingent relationships, learning about one stimulus can influence learning about other stimuli. For example, in blocking, learning that cue-A predicts an outcome can reduce learning about a subsequently added cue-B that is paired with cue-A when both cues predict the same outcome (Kamin, 1969). To the extent that spatial learning operates according to similar principles to other forms of contingency learning, spatial cues that can be used to locate a goal should also compete with each other. Failure to find blocking between spatial cues that can be used to locate a goal would be consistent with an alternative account of how spatial knowledge is acquired and used: one that assumes a quite different learning mechanism. For example, the hypothesis of *locale* learning assumes that a cognitive map of the environmental layout is automatically updated when cues are added or removed from the environment (O’Keefe & Nadel, 1978). Automatic updating implies that added or removed cues will be processed irrespective of what is learned about other cues, rather than competing with or otherwise interacting with those other cues. A second, related, hypothesis is that the geometric properties of the environment are processed in an independent module

that is impervious to cue competition from non-geometric features (Cheng, 1986; Gallistel, 1990). This hypothesis implies that geometric cues within the module are also immune to competition from each other.

In the current experiments, evidence for blocking of goal location learning was investigated in virtual environments (VEs) in which the presence or absence of large-scale structures can be manipulated. Experiment 1 found that an irregular-shaped flat-walled enclosure blocked learning about a landmark subsequently placed within its boundaries, providing preliminary evidence that shape may not be processed in a specialised module. However, many participants appeared not to be using shape to locate the goal. In the remaining experiments, spatial cues were large-scale 2D shapes presented on the ground which ensured that participants perceived overall shape. Experiments 2 and 3 found no evidence of blocking between shapes when these stimuli were presented in the context of minimal ‘auxiliary’ cues. When additional auxiliary stimuli were presented throughout learning in Experiment 4, a direction consistent with blocking was found, but the effect was not statistically significant. In Experiments 5 and 6 a clear blocking effect was found under circumstances that suggested that the critical variable to finding blocking was the number of irrelevant shapes present either during training or at test. Experiment 7 confirmed that, rather than the test conditions, the presence or absence of stimuli during one or both training phases was the crucial variable in promoting blocking. Experiment 8 investigated the hypothesis that an initial process of learning to ignore irrelevant shapes in phase 1 is a requirement for blocking of learning. In the absence of auxiliary cues in phase 1, blocking was not found. The implications of these outcomes are discussed in relation to the hypothesis of specialised geometric processing, changes in attention, and the conditions of discrimination learning.

CHAPTER 1

INTRODUCTION

Humans and animals must adopt strategies to gauge their constantly altering position within the environment if they are to successfully negotiate "that great God-given maze which is our human world".

Tolman, 1948, p.208

Overview: *Spatial and contingency learning*. The ability to respond appropriately to contingencies between events is fundamental to survival. In many species, learning mechanisms have evolved that enable organisms to anticipate the occurrence or non-occurrence of important events on the basis of environmental 'cues', or the organism's own behaviour (Mackintosh, 1983). Predictive relationships can either be causal or structural (e.g. Shanks, 1995), but a basic learning mechanism need not distinguish between the two. For example, a rat in a classical conditioning experiment will typically detect that the illumination of a light on the wall is regularly followed by food and it will approach the food magazine as a consequence. However, it is irrelevant to the rat that the light does not actually cause the delivery of food. For survival purposes, animals typically need to learn only whether one event signals an increased or decreased probability of a significant event, given the presence or absence of other potential signals for that event.

In many species, including humans, a second fundamental ability that confers a major survival advantage is the potential to locate a goal. The cues and landmarks that are available in most environments are varied and support goal localization in a number of ways. Evidence suggests that moving to a goal that is immediately adjacent to a landmark requires a different spatial learning mechanism (approach) to that involved in moving to a goal that is distant from available landmarks (piloting). Thus, spatial learning in general might rely on specialised mechanisms that differ from those involved in predictive learning (O’Keefe & Nadel, 1978). The aim of this thesis is to investigate whether there is evidence for the operation of a common mechanism or mechanisms in human spatial and predictive learning under conditions in which spatial learning might be most likely to differ from other forms of contingency learning.

At the outset of this research programme this issue of a common learning mechanism for spatial and other contingent relationships was being investigated primarily in the context of associative learning procedures in non-human animals. In associative learning, a crucial finding is that the presence of cue-A can influence what is learned about cue-B. Accounts of the mechanisms that underpin such ‘cue-interactions’ were, and largely still are, couched in terms of associative learning (Mackintosh, 1983), but other knowledge structures might be involved (Shanks, 2007). In experiments in which cue-interactions were found between landmarks (spatial ‘cues’) when locating a goal (equivalent to the ‘outcome’ in predictive learning), this was considered evidence of the operation of an error-correcting associative learning mechanism. Failure to find evidence of cue interactions was taken as evidence against the operation of an associative mechanism, and by default as supporting a different kind of spatial knowledge structure referred to as a cognitive map (O’Keefe & Nadel, 1978).

At this time, evidence for competition between landmarks was beginning to accumulate in both the human and animal learning literature (see Chamizo, 2003), suggesting a common associative learning mechanism for spatial and temporal contingencies. However, attempts to demonstrate cue competition were not always successful in animals, particularly where the shape of the enclosure being explored served as one of the ‘cues’. This finding forms the basis of the experiments with people reported in this thesis.

The history of experimental studies of spatial learning in animals stretches back at least to the first half of the 20th century when experimenters such as Tolman (1948) and Hull (1943) investigated single unit T-maze learning in rats, and proposed that learning about goal locations could be achieved by different strategies. For Tolman, rats learned about a *place* where the goal box containing food was located e.g. “under the window, to the left of the radiator etc” (Tolman, Ritchie & Kalish, 1946, p 221). Tolman went on to describe *place* learning in terms of a cognitive map, a concept implying knowledge about a specific place in space, such that “in the course of learning something like a field map of the environment gets established in the rat’s brain” (Tolman, 1948, p192). However, later experiments demonstrated that learning to reach a goal in a maze need not be based on place learning. For example, it can be based upon Pavlovian conditioning, where either the physical characteristics of the goal box containing food or extra-maze cues in its vicinity, become associated with the presence of an appetitive stimulus such as food. Classically elicited approach to the box with the correct characteristics or visual cues would ensure that the goal is reached (Mackintosh, 1974, 2002).

An alternative influence on reaching a goal is instrumental conditioning in which the rat can find its way through the maze by learning to make a correct response at each junction, e.g. turn left at the second junction, would result in finding the food box. In this learning procedure, discovering food is said to reinforce the correct response (Hull, 1943). The importance of classically elicited responses was not recognised by early learning theorists, and ‘place’ versus ‘response’ theories were tested in several experiments in the T-maze. The majority of experimenters concluded in favour of place-learning. However, there were many exceptions that suggested that instrumental response learning increased when the available visual cues were diminished. As Restle (1957) pointed out, there was nothing in the nature of the rat that made it exclusively a “place” learner or a “response” learner, and the adopted mechanism was dependent on available cues in the environment.

Animals and humans are constantly faced with events that may or may not reliably predict an outcome, whether that is knowing a certain food will cause illness, making a choice at a decision point, or moving to a goal with reference to cues or landmarks. In all of these examples there must be a mechanism governing the detection of correlations between events. For most animal researchers the mechanisms underlying these abilities fall under the umbrella of associative learning.

1.1 Associative Learning

Explaining the process by which animals discover how one event reliably predicts another is the task of contemporary associative learning theories. Up until the late 1960s the most important factor thought to influence how one event or cue, a conditioned stimulus (CS), would become associated with an event of importance, an unconditioned stimulus (US), was that the latter should follow the former close together in time. Put simply, temporal contiguity leads to the formation of associations between areas or functions of the brain with overlapping activity. For example, according to Pavlov (1927), if a noise (CS) repeatedly activates an auditory part of the brain just prior to a flavour of food (US) activating a flavour sensitive region that innately causes salivation (an innate ‘unconditioned’ response, or UR), then evidence for an association between the CS and the US can be recorded as a conditioned response (CR). Even though the tone has no innate qualities that cause salivation, after the contiguous CS-US pairings the relationship between tone and food representation allows the presentation of the tone alone to cause salivation. This example of ‘classical conditioning’ suggests that contiguity between events is crucial to the establishment of associations.

Kamin’s (1969) experiments that introduced the phenomena of “blocking” provided evidence that temporal contiguity between CS and US is not sufficient to establish a CR. In his experiments, comprising more than 110 experimental groups and 1200 rats, he first trained rats to press a bar for food so that over a period of days they reached a stable level of bar pressing. For the CS he used either a white noise or a light or a simultaneous compound presentation of noise and light. The CSs could be immediately followed by an electric shock, with learning about the CS being measured by how much lever pressing was suppressed in comparison with an equivalent period just prior to the CS. The basic design (see Table 1.1) was initially to present the experimental group with a single CS, e.g. noise, followed by shock until asymptote (a maximal stable level of lever-press suppression) was reached, then to present a compound of noise and light followed by shock in the second phase of training.

Group	Phase 1	Phase 2	Test
Experimental	noise -> shock	noise + light -> shock	light
Control	(no events)	noise + light -> shock	light

Table 1.1 Blocking experiment design (Kamin, 1969).

Learning about the stimulus added in phase 2 was tested by presenting it alone in the test. Performance in the test phase was compared to a control group who did not have the initial single element training, but were trained only with the compound of noise and light. The blocking outcome was that in the test the experimental group showed significantly less suppression than the control group, indicating that the initial training with the single stimulus had interfered with or “blocked” learning about the subsequently added stimulus in phase 2. The blocking result highlights that although both groups had exactly the same temporal arrangement of stimuli in phase 2, and the same context of learning and testing for the tested cue, learning about that cue was not equivalent. The rats in the experimental group learned something that made them behave as though the added stimulus in phase 2 was not as good as a predictor of the shock as it was for the control group.

Another form of cue competition which also raises the problem of the insufficiency of temporal contiguity is overshadowing in which less is learned about cue-A if it is trained with another cue, B, than if A is trained on its own (Pavlov, 1927). One variation on this form of cue competition was shown in Wagner’s (1969) experiment on eyelid conditioning in rabbits: he found that learning about a CS in a compound was dependent upon the relative validity of the other CS as a predictor of the US. Other examples of behaviours which indicate that temporal contiguity is not sufficient to explain associative learning include: latent inhibition (Lubow, 1973) where learning that a CS predicts a US is retarded if the CS has previously predicted nothing; Pavlovian inhibition, in which responses suggest knowledge that a stimulus cancels or reduces the probability of an important event that would otherwise have occurred (Hearst & Franklin, 1977); learned irrelevance occurs when CS and US are presented in a random relationship which leads to very slow subsequent learning of a consistent CS - US relationship (Baker & Mackintosh, 1977). All of these learning phenomena confirm that temporal contiguity alone is not sufficient to explain even animal associative learning.

1.2 Theories of Associative Learning

We have seen that temporal contiguity alone is not a sufficient mechanism to account for associative learning. Whilst contiguity is still important, contemporary associative learning theories have stressed the importance of surprise, and that the more surprising or unexpected a US is then the more is learnt about it and other temporally contiguous events. According to the Rescorla-Wagner model (Rescorla & Wagner, 1972) associative learning relies upon temporal contiguity between the CS and US, together with surprising or unexpected presentations or omissions of the US. A US is surprising when there is a difference or discrepancy between the physical US that is presented on a trial and the US that is predicted by all the CSs that are present on the trial. The degree of discrepancy is hypothesized to drive the amount of rehearsal of the immediately preceding events. According to an associative account, during the rehearsal of the contiguous events the association between the CS and US grows in strength. Therefore, the largest increase in associative strength occurs on the first trial when surprise is greatest. As pairings continue, the association continues to increase but to a lesser extent because its growth leads to a decrease in surprise and rehearsal of immediately preceding events. Eventually learning reaches asymptote when there is no discrepancy between the actual US and the memory of the US that the CS-US connection activates i.e. there is no more surprise to trigger rehearsal.

Rescorla and Wagner (1972) set out the change in associative strength that could occur on any given trial (Equation 1.1). λ represents the maximum conditionable associative strength of the US and Vx indicates the summed strength of the associations from all CSs present on a trial to the US. The difference between the two values on a given trial represents the extent to which the US is surprising. Salience of the CS and US is determined by the inclusion of a learning rate parameter α, which is set between 0 and 1, is a constant throughout conditioning and influences how rapidly learning proceeds. ΔV_A represents the change in associative strength between a particular CS, (e.g., CS_A) and US on any trial.

$$\Delta V_A = \alpha (\lambda - Vx) \tag{1.1}$$

Assuming an α value of .2 and a US with an arbitrary λ value of 100 units, the growth in associative strength between a US and a single CS on the first trial is set out in Equation 1.2. Note that V is zero on this first trial as it is the first CS-US pairing, so no strength has yet been established and the level of surprise is maximal (100 – 0 = 100). At the end of the first trial the associative strength of the CS is 20 units.

$$\Delta V = .2\ (100-0) = 20 \tag{1.2}$$

On the second trial (Equation 1.3) the associative strength of the CS established on trial one is entered into the equation so that by the end of the trial a further 16 units of associative strength has been accumulated by the CS. The level of surprise is not as great as on the first trial (100-20=80).

$$\Delta V = .2\ (100-20) = .2 \text{ x } 80 = 16 \tag{1.3}$$

The total associative strength accumulated by the end of trial two is 36 units: 20 units from trial one and 16 from trial two. As learning proceeds there is a negatively accelerated growth in associative strength as the level of surprise diminishes. Eventually when there is no discrepancy ((λ-V) = (100-100), the associative strength is maximal and learning ceases.

1.3 Application to Blocking

The Rescorla-Wagner model can account for the blocking effect found in Kamin’s (1969) experiments. According to the model, at the end of phase 1 training with a single CS for the experimental group (Table 1.1), a full strength association between the noise and the shock will have been established. By the end of phase one, no new learning occurs because the noise activates a full strength memory of the shock; no discrepancy means that the learning mechanism is not activated. In phase two, a novel stimulus (the light) is presented in compound with the noise. As the noise has already established a full strength association with the shock, when it is presented with the light in phase two it will still activate a full strength memory of the shock. As the shock is not surprising there is no rehearsal and consequently no new learning occurs; therefore the noise blocks learning about the light. In comparison, the control group experiences both noise and light for the first time in phase 2, and the surprise of the novel shock leads to rehearsal of both of the immediately preceding events. This results in learning about both CSs equally, as the associative strength is shared between them.

Rehearsal of preceding events is not the only mechanism that has been proposed to explain cue-competition effects. Attentional theories have offered an alternative view of how surprise might operate. Mackintosh (1975) suggested that a change in an animal's attention to a CS can explain phenomena such as blocking. Mackintosh's theory suggests that animals will pay more attention to stimuli that have a higher associative strength than others, and will actively ignore stimuli with lesser associative strength. In the Rescorla-Wagner model the learning rate parameter, α, is a constant that can range between 0 and 1 and is dependent on the physical salience of the CS and US. The larger the value of α then the faster the rate of learning. In Mackintosh's theory α also influences how rapidly learning proceeds, but in addition to physical salience it reflects the amount of attention paid to a specific CS. Attention to a stimulus can increase or decrease as learning proceeds depending on how good a predictor of an event of importance (US) it is compared to other stimuli present. The formula governing this learning is set out in Equation 1.4. $\Delta\ \alpha_A$ represents the degree to which attention to CS_A changes, and depends on the amount of associative strength that has accrued to CS_A compared to other stimuli (X). λ, as in the Rescorla-Wagner model, is the maximum conditionable associative strength of the US, and V_A the current associative strength of the CS. Vx is the associative strength of all stimuli other than CS_A. When $\lambda - V_A$ is small, CS_A must have a strong association to the US, and when $\lambda - V_x$ is large, CS_X must have a weaker association.

$$\Delta\ \alpha_A \text{ is positive if } \quad |\lambda - V_A| < |\lambda - V_x| \qquad (1.4)$$

$$\Delta\ \alpha_A \text{ is negative if } \quad |\lambda - V_A| \geq |\lambda - V_x|$$

The formulae illustrate that when greater associative strength has been acquired by V_A compared to V_x, (λ - V_A is smaller than λ - V_x), attention to V_A will increase i.e. $\Delta\ \alpha_A$ becomes more positive. Conversely, attention to V_A decreases and $\Delta\ \alpha_A$ becomes more negative if less associative strength has been acquired by V_A than V_x i.e. λ - V_A is larger than λ - V_x. In Equation 1.5, ΔV_A represents the change in associative strength between CS_A and the US on any trial, and α_A reflects the amount of attention that CS_A receives as determined above (Equation 1.4). The greater the value of α_A then the more rapid learning will be to $CS_{A.}$

$$\Delta\ V_A = \alpha_A\ (\lambda - V_A) \qquad (1.5)$$

Applying the theory to a blocking example: In phase one training in which a light is followed by food, on the initial trial the light will attract attention because of its novelty and physical salience. Over a number of trials the associative strength between the light and the food will increase. Background stimuli will also be present when food is delivered, but any associative strength that develops to them (because they too are present when food is delivered), will extinguish during the inter-trial intervals when no food is delivered. As the associative strength of the light will rapidly increase and become greater than that of the background stimuli, attention to the light will increase, and the background cues will be ignored. A tone is then introduced in phase two which, on the first trial, will also attract attention due to its intrinsic properties. However, as the light has already been established as a better predictor of the food, attention to the tone will diminish on subsequent trials. Blocking of learning about the added stimulus occurs after the first trial as attention to it diminishes.

For the control group, there will be no initial associative strength between the light and food, or between the tone and food because they are experienced for the first time in phase two. As there is no discrepancy between their associative strengths, and no other stimulus with a greater associative strength is present, attention to them both will be maintained, or will decline equally and slowly.

Therefore, Mackintosh’s theory predicts blocking, but on the basis of future modulation of attention to the CS rather than rehearsal of prior events. The theory implies that conditioning on the first compound trial with the new stimulus will proceed normally, and that it is only as attention to it diminishes on subsequent trials that blocking emerges. In contrast, the Rescorla-Wagner (1972) model proposes that learning about the new CS will be attenuated from the outset of the training with compound trials.

Both theories are ‘error-correcting’ accounts, as they maintain that learning is dependent on the discrepancy between predicted and actual USs, and that the mechanism of learning lies in correcting this error. According to Rescorla & Wagner (1972), blocking occurs because the added CS is not rehearsed when it occurs along with a pre-trained CS that fully predicts the US; no rehearsal occurs when there is no error. According to Mackintosh (1975) the discrepancy between the actual and predicted US (error) is smaller for the pre-trained CS which has high associative strength, than for the added CS which has no associative strength. Attention increases to the CS that leads to the smallest error or discrepancy, and decreases to CSs that lead to greater error.

1.4 Application to spatial learning

The theories of the mechanisms that govern how CS-US associations develop suggest how probable causal relationships come to be mentally represented and chance co-occurrences of events do not. The crucial finding from the blocking experiments is that stimuli can compete with each other as predictors of important events. This is a fundamental capacity required to learn true causal relationships as opposed to registering all chance conjunctions between events. In the animal literature, interest has not been restricted to processes that govern learning with traditional temporal arrangements of visual, auditory or gustatory stimuli. Associative learning theories such as the Rescorla-Wagner model have provided the impetus to consider whether the processes involved in classical and instrumental conditioning can apply more generally to spatial learning (see Miller & Shettleworth, 2007).

Many studies of spatial learning have found competition between spatial cues as indicators of a goal location which seems to parallel learning about CSs and USs. In a study with pigeons (Spetch, 1995), learning about two visual target cues as goal location indicators was measured; learning about a landmark that was closer to the goal than other landmarks overshadowed learning about one that was further away. In another example, Cheng and Spetch (2001) found blocking in honeybees that were initially presented with a single landmark in a constant relationship to a target (sugar water) followed by compound training involving a second landmark. Experiments with rats have also found evidence of cue competition in the spatial domain. For example, Rodrigo, Chamizo, McLaren, and Mackintosh (1997; see also Sanchez-Moreno, Rodrigo, Chamizo, & Mackintosh, 1999; Rodrigo, Arall, & Chamizo, 2005) found that if rats in a water maze were trained to find a hidden platform with three distal cues present, they learned less than a control group about an added distal landmark (see Chamizo, Manteiga, Rodrigo, & Mackintosh, 2006, for a related outcome). In a study by Biegler and Morris (1999) rats were trained to find food hidden under wood shavings on the floor of an arena. The only unambiguous cues to aid learning were landmarks placed at distances between 50 and 100 cm from the goal location. It was found that for the experimental group, initial training with a landmark blocked learning about a subsequently added landmark. In other experiments, local cues have been found to compete with distal cues. For example, in a three-arm maze experiment with rats, Diez-Chamizo, Sterio and Mackintosh (1985; also March, Chamizo & Mackintosh, 1992) found that when both local cues (textures on the arms) and distal cues predicted where food could be found, less was learned about each type of cue than when presented alone.

Further evidence that spatial cues local to the target can interfere with distal cues has been found in experiments using rats and the water maze. Morris (1981) trained rats to find the safety of a platform within a circular pool of opaque water. Distal cues were available to all rats, but for one group the platform was visible above the surface of the water; therefore escape from the pool could be achieved merely by approach to the visual features of the goal, a process otherwise known as beacon approach. In the test, the platform was removed and it was found that the beacon-approach group spent less time in the correct quadrant of the pool than a group that had been trained with a platform just below the surface of the water (and therefore invisible). This suggests that for the beacon- approach group, the visible local cue had interfered with learning about the distal cues. Further studies have adopted the use of the Morris pool to demonstrate interference between spatial cues. For example, Redhead, Roberts, Good, and Pearce (1997) found that a beacon attached to a hidden platform interfered with learning about distal cues, and Roberts and Pearce (1998) replicated this effect when the platform and local beacon cue moved from trial to trial. Spatial learning experiments of this nature are comparable in design to more traditional cue competition experiments in which stimuli such as noises and lights that predict an outcome can compete with each other as signals for an outcome.

The question of whether associative learning mechanisms also apply to spatial learning in humans has been addressed to a limited extent using computer technology. This involves the creation of computer-generated, virtual environments (VEs) that are typically presented on a standard desktop monitor. This technology allows the simulation of 3D environments by imitating perspective and depth cues that might be found in the real world. Exploration in these VEs can be achieved using a keyboard or joystick that enables the user to interact with the environment in real-time. Several studies of spatial learning have used virtual versions of the Morris water maze (VMWM). Hamilton and Sutherland (1998) used abstract 2D cues presented on the walls of a computer-generated, square room as location cues. Just as rats had to swim in the real Morris pool, participants had to navigate in a circular pool within the room and locate a hidden platform. They found that initially training one set of abstract cues to predict the goal blocked a second set of cues presented in compound with the initial set. Chamizo, Aznar-Casanova, and Artigas (2003) found overshadowing in human participants who also searched for a goal in a VE enclosure using four distal cues as landmarks. The distal landmarks were individual objects suspended above the enclosure walls. The background beyond the enclosure was black ensuring that only the landmarks provided localization cues. For half of the participants the platform was visible and for the remainder it was invisible. Thus for the visible-group, there was the opportunity to learn about both cue types, proximal to or distal from the goal. In the test the platform was removed for both groups and the time spent in the quadrant of the enclosure where the platform had originally been located was recorded. The outcome was that the visible-group spent less time in the correct quadrant than the invisible-group. The conclusion was that if the platform was visible during initial training it overshadowed learning about the distal landmarks. The authors did however recognise a potential problem with their design that suggested that the difference in performance could be explained in terms other than overshadowing. Poorer performance by the visible group could also be explained in terms of generalisation decrement (Rescorla & Holland, 1982), which occurs when responding to a stimulus in a test is weakened if the elements in the test differ from those present in prior training. For the visible-group, the change between the initial training and test phase was greater than for the invisible group. The invisible-group had one set of distal cues during training and exactly the same in the test, whereas the visible-group had the proximal cue and the distal cues during training but only the distal cues in the test. In a further experiment to address this issue the authors presented two visible platforms to both groups in initial training and in the test. For the experimental group the platforms were coloured differently so that a platform of a certain colour consistently predicted escape. The control group also had two platforms but they were the same colour, so escape could only be achieved successfully with reference to the distal cues. Ruling out a generalization decrement explanation, overshadowing of the distal cues by the proximal cue was again found.

Cue competition has not been found in all VE experiments. Using a similar design to the first experiment by Chamizo et al (2003) described above, Jacobs, Laurance and Thomas (1997) failed to find overshadowing of distal cues embedded in surrounding walls that formed a square by a local visible cue proximal to the goal. The design of the experiment leaves open the possibility of generalization decrement. That overshadowing did not occur in spite of the potential for generalization decrement in the experimental group seems to suggest a convincing case of failure to find cue competition. Although there are few human spatial learning studies that have investigated cue competition it appears that effects consistent with associative learning principles can be found, but these may depend on the nature of the experimental design and stimuli used.

1.5 Cognitive Maps

The evidence set out in the previous section provides some indication that, across species, spatial learning appears to be governed by mechanisms similar to those that govern other forms of contingency learning. This position is challenged by O'Keefe and Nadel (1978) who used Tolman's (1948) term 'cognitive map' to describe a hypothetical representation of the environment based on integrating allocentric cues. O'Keefe and Nadel made the distinction between two spatial learning systems. The main system: "the hypothesis of the cognitive map" they call *locale* learning which can be viewed as "true spatial learning". It is claimed that this type of learning is highly flexible and can be used to plan routes, and guide shortcut decisions. Locale learning is proposed to operate in a non-associative manner which, in response to novelty within the environment, leads to learning in an all-or-nothing way. Any mismatch between the currently experienced environment and the existing representation of that environment prompts the cognitive map to be updated. The importance of this for theories of learning is that it implies that if cues or landmarks are added to or taken away from the environment, information about them is automatically updated. In contrast to 'discrepancy' theories (e.g. Mackintosh, 1975; Rescorla & Wagner, 1972), the locale system operates in accordance with automatic or incidental-learning principles similar to that described by Hebb (1949). Blocking between landmark and other spatial cues should not occur according to the cognitive map theory.

Further, O'Keefe and Nadel (1978) propose that the hippocampus is the brain structure responsible for managing this type of spatial information. Although not directly relevant to the experiments in this thesis, physiological studies with rats have found that specific 'place cells' in the hippocampus fire according to the location of the animal within its environment (e.g. Muller, Bostock, Taube & Kubie, 1994). Specific 'head direction cells' in the hippocampus are also thought to enable a rat to determine the position of its head within the environment (e.g. Taube, Muller & Ranck, 1990). This provides orientation information that is independent of location. Studies with humans have found related evidence pointing towards the importance of place cells (Ekstrom et al 2003) and the hippocampus (Bohbot, Iaria & Petrides, 2004;Iaria, Petrides, Dagher, Pike & Bohbot, 2003) in spatial learning.

Evidence consistent with O'Keefe and Nadel's (1978) hypotheses of a cognitive map is provided by the ability of animals to find goals with reference to distal cues. Piloting is employed when the goal location cannot be perceived directly but can be established by reference to distal landmarks. Piloting requires the integration of vector information about the position of landmarks and the goal with regard to the navigator's current location (Cheng, 1989; Collett, Cartwright, & Smith, 1986; Gallistel, 1990). However, it is not clear that the hypothesis of a cognitive map adds to our understanding of piloting.

The second system proposed by O'Keefe and Nadel (1978) is the taxon system which they subdivided into orientation and guidance learning. By orientation they refer to response learning which for a rat in a T-maze might be to turn left or right at a choice point, basically a form of instrumental conditioning. Guidance learning is a form of classical conditioning where a rat in the maze, for example, associates the goal box stimulus with the presence of food. In a similar way, in the Morris pool, guidance learning occurs when a beacon is attached to the hidden platform and the rat associates the beacon with escape from the pool (e.g. Roberts & Pearce, 1998). Neither orientation nor guidance learning involves true spatial learning of the sort that is required when piloting to a hidden location at a distance from relevant landmarks. Given that taxon learning relies on mechanisms that operate during classical and instrumental conditioning, the implication is that associative learning phenomena such as blocking should be found when this system is engaged.

1.6 Use of geometry in location learning

In experiments with animals it has been found that locations can be learnt with reference to cues supplied by the shape of the environment. Cheng (1986) trained rats in a rectangular arena that had distinctive landmarks in each corner. Despite the presence of these landmarks there was evidence that the overall shape of the arena gained control over search behaviour. Primarily this involved rats making rotational errors such that they would persist in searching in the correct and diametrically opposite corners of the arena rather than using a distinctive feature near the correct corner. In test trials, the rats searched in the corners that had the same geometric properties. The importance of environmental geometry was addressed by Gallistel (1990) who suggested that the shape of the environment will always be used as a reference for finding a hidden goal. Gallistel emphasised the difference between geometric and featural properties:

‘A geometric property of a surface, line, or point is a property it possesses by virtue of its position relative to other surfaces, lines, and points within the same space. A nongeometric property is any property that cannot be described by relative position alone.’ (Gallistel, 1990: p212)

Cheng (1986) and Gallistel (1990) propose that learning about geometric properties takes place within a dedicated module that is impenetrable to nongeometric featural information. The independence of shape learning implies that non-geometric features of the environment do not influence the control that shape gains over goal-finding behaviour. The a priori prediction that follows is that cue-interactions should not occur between environment shape and other featural cues. Cue competition studies with animals lend some support to this notion in that the presence of a cue or feature close to a hidden location often does not overshadow or block learning about environment shape (Brown, Yang & DiGian, 2003; Hayward, Good & Pearce, 2004; Hayward, McGregor, Good & Pearce, 2003; Kelly, Spetch & Heth, 1998; Pearce, Ward-Robinson, Good, Fussell & Aydin, 2001; Wall, Botly, Black & Shettleworth, 2004). The failure to find an interaction between learning about shape and other features is also compatible with O'Keefe and Nadel's (1978) theory that spatial cues are automatically updated. Neurological support for geometric specialisation has suggested that the hippocampus may be tuned to geometric information: Lever, Wills, Cacucci, Burgess and O'Keefe (2002) tested rats in square and circular enclosures and found that firing patterns in place cells diverged with experience according to the shape of the environment. Furthermore, the pattern of activity was maintained over a long period of time. The implication of this study is that the hippocampus is tuned to processing geometric information.

Consistent with the idea that dedicated brain structures may process geometry, Vallortigara, Pagni, and Sovrano (2004) showed physiological asymmetry in geometry processing in domestic chicks. Chicks were trained to find food in one corner of a rectangular enclosure with distinctive panels in each corner (see Figure 1.1 for a similar design in human subjects). In the test, the panels were removed and the chicks searched either using left, right or both eyes. It was found that when using only the left eye, which projects to the right hemisphere, rotational errors were made that showed a preference for using the geometric properties of the enclosure.

A further account suggesting a special status for location learning based on shape was proposed by Wang and Spelke (2000; 2002), who found that following disorientation, people retain more accurate configural knowledge for room corners than for arrays of objects. According to Wang and Spelke, object locations are processed egocentrically, with respect to the view of the observer, whereas the relationships provided by room-shape are processed allocentrically, with respect to static distal features.

Various methods have been used to investigate the processes underlying spatial learning in humans and specifically to explore the extent to which geometric properties gain control over behaviour. Experimental environments have included both large and small scale real world enclosures (e.g. Hermer & Spelke, 1996; Learmonth, Newcombe & Huttenlocher, 2001) and table top layouts (Gouteux, Vauclair & Thinus-Blanc, 2001). The focus of these studies has been on the developmental aspects of spatial learning, and have typically involved children up to the age of six years and as young as eighteen months. Further studies have used both child and adult samples to compare developmental maturation (Hermer & Spelke, 1994,1996; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Gouteux & Spelke, 2001; Gouteux et al, 2001; see Cheng & Newcombe for a review, 2005).

Hermer and Spelke (1994, 1996) used a small room in which children and adults had to learn a target location e.g. the whereabouts of a hidden toy, in one of the corners. The room was rectangular and one of the walls was coloured blue. Thus two types of cue were available to aid learning. The shape of the room provided geometric information in terms of the length of walls and angles at the corners. In order to determine if corners are geometrically equivalent in such an environment it is also necessary to have a sense of the difference between left and right i.e. to encode when a long wall is to the right of a short wall or vice versa. Reference to Figure 1.1 illustrates that reliance on the geometric properties of the room at the expense of the blue wall can lead to geometric ambiguity. That is, if the target location is at corner A and learning is based solely on geometry, search after disorientation will be concentrated in corners A and D. This is because these corners are geometrically ambiguous i.e. both have a long wall to the right and short wall to the left. Hermer and Spelke found that young children made this error by searching in the correct location C and its rotational equivalent, location R. Older children and adults however did not make such rotational errors and focussed their search on the correct location C close to the coloured wall. These results were interpreted as evidence that children share an encapsulated geometric module with other species but that this is overridden as language develops (Hermer-Vazquez, 1997; Hermer-Vazquez, Spelke & Katsnelson, 1999).

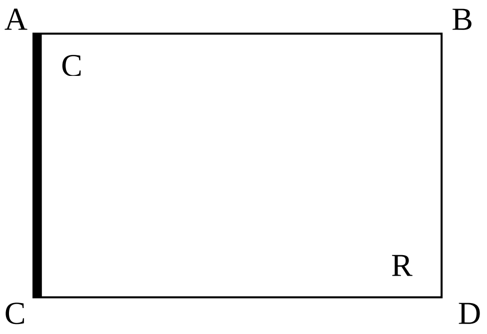

Figure 1.1. Illustration of the rectangular room used by Hermer and Spelke (1994; 1996). C is the correct search location and R indicates the location subject to rotational error. Wall A-C was coloured blue and all other walls were white.

Learmonth et al (2001) also found an apparent preference for the use of geometric information by children who made similar rotational errors in a rectangular room of the same size as that used by Hermer and Spelke (1996). However, when the room size was increased this preference disappeared (see also Learmonth, Nadel & Newcombe, 2002; and Vallortigara, Feruglio & Sovrano, 2005 for a similar finding with domestic chicks). Further studies with children using similar types of environments have indicated that geometry is not necessarily dominant over other features or landmarks (Hupbach and Nadel, 2005; Twyman, Friedman and Spetch, 2007) and that young children can use coloured walls as well as geometry to orient (Nardini, Atkinson & Burgess, 2008). Wang and Spelke (2002) suggested that early sensitivity to geometric information is restricted to the permanent surrounding surface layout, in other words, walls or boundaries seen by the viewer from within an environment. However, Huttenlocher and Vasilyeva (2003) found that this was not necessarily the case. They tested children using an isosceles triangle shaped environment and found that children were able to use the geometric properties of the environment both from within, when surrounded by the walls, and externally when they viewed the space from outside.

These studies provide some support for the notion of a specialised geometric module in cases where the shape of the enclosing structure is little affected by other features. However, much of this work has been undertaken with children and, in the designs used, the effect tends to disappear in older children and adults (Gouteux et al, 2001; Hermer & Spelke, 1994, 1996; Hermer-Vazquez et al, 1999). An additional factor that limits interpretation of the existing data is that appropriate controls for cue-interaction effects have rarely been employed. When participants have been trained both with shapes and features, efficient learning about shape has often been found. However, what has been lacking is a control group that only experiences shape. It could be, for example, that such a group would perform less well than a group experiencing shape and features concurrently. Indeed, animal research has found that additional features sometimes enhance or facilitate learning about shape (see Kelly, Robak & Kamil, 2004; Pearce et al, 2001; Pearce, Graham, Good, Jones & McGregor, 2006).

There have been few experiments with humans that have specifically looked for cue competition between environment shape and a feature and included an appropriate control group. Using a virtual environment in the shape of an isosceles triangle, Redhead and Hamilton (2007) investigated whether a visible target platform interfered with learning about shape. Participants had to find the correct escape location on one of two visible platforms near the base corners of an isosceles triangle shaped enclosure. For the experimental group the escape location was consistently either on a platform coloured white or another coloured black. The correct platform location did not vary, so escape could be achieved either with reference to the platform or the properties of the environment shape. For the control group, the two platforms were both coloured black so only the shape of the enclosure gave unambiguous location information. The extent of learning to the shape was tested by removing the platforms for both groups. It was found that the experimental group performed as well as the control group, indicating that the presence of the relevant visible platform during training failed to overshadow learning about the shape of the enclosure. This lack of cue competition supports some of the findings in the animal literature where features have failed to compete with environment shape (e.g. Esber, McGregor, Good, Hayward, & Pearce, 2005; Hayward et al, 2003).

1.7 Research question

Although there is evidence consistent with the independence of shape learning from experiments with both in animals and humans, the influence of other cues remains unclear. Several studies in the animal literature that have introduced shape as a cue have found results inconsistent with the proposed modularity of geometry learning. Using a Morris pool shaped like a kite, Graham, Good, McGregor and Pearce (2006; also Pearce et al, 2006; Tommasi & Polli, 2004) compared groups of rats who had to find a submerged platform that was consistently in one of the two right-angled corners. One group could use the shape of the enclosure and featural cues to locate the platform. The featural cue in the experiment was the colour of two of the walls. The second group could also use the shape of the enclosure but the coloured walls were made irrelevant by alternating their position. Thus for the first group, shape and colour were both relevant, whereas for the second group, only shape was relevant. The extent of learning about shape was measured in the test by making all walls uniform in colour. The key finding was that the shape and colour group showed a preference for searching in the correct corner compared to the shape only group. This indicated that the presence of the coloured wall in the shape and colour group enhanced learning about the shape of the pool (see also Kelly, et al., 2004 who found a similar facilitation effect in pigeons).

The a priori prediction from associative theories in this comparison is that cue competition, rather than facilitation of learning, should occur. This is because the differing colours of the walls were correlated with the target location, which should allow this feature to overshadow the shape. Facilitation of shape learning by additional features could be similar to an effect occasionally found when learning about more conventional cues such as tastes, and for which associative accounts of facilitation have been proposed (Bouton, Dunlap & Swartzentruber, 1987; Rescorla & Durlach, 1981). Overshadowing of shape-learning by another distinct feature (coloured walls) has been demonstrated in chickadees (Gray, Bloomfield, Ferrey, Spetch, & Sturdy, 2005) and in rats (Pearce, et al., 2006). Pearce et al. (2006) found that colouring individual walls facilitated learning in a kite-shaped enclosure, but overshadowed and blocked learning in a rectangular enclosure.

Pearce, Good, Jones, and McGregor (2004) suggest that some apparent demonstrations of target location learning based on shape may be accounted for in terms of learning local features or response strategies, rather than overall shape (also Esber et al, 2005). Pearce et al. trained rats to find a submerged platform in one corner of a four-sided enclosure, prior to transfer to a second four-sided enclosure of a different overall shape. In the second enclosure, searching for the platform was most efficient when the target was in a corner that was geometrically equivalent to the corner that was correlated with the platform location in the first enclosure. As the overall shape of the enclosures differed, this outcome suggests that the rats found the platform by matching local features rather than using overall shape. The mixed evidence found when shape could have been used as a cue demonstrates the need for caution before inferring a specialist geometric module.

The proposal of Cheng (1986) and Gallistel (1990) is that geometric processing occurs in a dedicated system that is unaffected by featural information. Evidence of interactions between concurrently available shapes in location learning would undermine the value of an account of spatial learning in terms of the independence of shape and other features. Such an account implies that if shape is processed within a dedicated and encapsulated module, cue competition should not occur, whether this involves shape competing with features or shape competing with shape. Compared to the animal literature there have been relatively few well-designed studies with humans that have investigated competition involving shape, and even fewer have attempted to consider shape as a spatial cue. There have been no attempts, either in humans or in other animals, to ascertain whether location learning based on one shape can interact with location learning based on another shape in accordance with error-correcting learning principles. The experiments in this thesis aimed to address this question by establishing firstly, whether one shape can compete with another feature, and secondly, whether shapes can compete with each other as predictors of a target location.

Evidence that shape can block other cues, and other cues can block shape, would undermine the hypothesis of a specialised geometric module, and would suggest that error-correcting learning rules are sufficient to explain the mechanisms that govern spatial learning, even true spatial learning. Evidence of blocking would also undermine a major prediction from the hypothesis of a cognitive map: that it depends on automated, incidental-learning processes that are immune to cue competition during true spatial learning. Failure to find evidence for shape blocking other cues and other cues blocking shape would suggest that processing of geometric relationships is conducted within a dedicated system that is unaffected by featural information.

CHAPTER 2

CUE COMPETITION BETWEEN ENCLOSURE SHAPE AND A LOCAL LANDMARK

2.1 The use of Virtual Environments to study spatial cognition

VEs simulate a 3D visual world that participants are able to explore from a first-person perspective in real-time. They also allow users to interact with and learn about objects in the virtual world (Kalawsky, 1993) and potentially learn about locations in a similar way to real world exploration. Since the 1990s the advent of more sophisticated computer hardware and software has lead to an increase in the use of VEs to investigate how human participants navigate and explore. It is a key requirement of a VE for research that it stimulates or enables behaviour that would occur in the real world. Failure to meet this prerequisite will naturally limit the conclusions drawn from this mode of presentation. The goal of any system presenting VEs is to provide environments that give the user the sense of being present in the simulated world (Steuer, 1992). A potential limiting factor of using desktop VEs is that they typically fail to provide the proprioceptive and vestibular feedback that would be encountered in a real world environment. Ruddle and Lessels (2006) found that in a very complex small scale VE, learning proceeded more efficiently when proprioceptive and vestibular feedback were available than when information was acquired based purely on simulated optic flow. It has also been found however that the availability of proprioceptive information may give little advantage when navigating a complex virtual maze (Ruddle

& Peruch, 2004), that optic flow alone is sufficient to enable efficient navigation (Riecke, van Veen & Bulthoff, 2002) and that learning through rotational movements is unaffected by the lack of vestibular feedback (Tlauka, 2007). Furthermore, several studies have found that learning transfers efficiently between real world and virtual equivalents (Bliss, Tidwell & Guest, 1997; Ruddle & Peruch, 1997;Wilson, Foreman & Tlauka, 1996, 1997) suggesting that similar cognitive mechanisms are involved in both domains (Richardson, Montello & Hegarty, 1999). Other studies, directly relevant to the present experiments, have shown that human behaviour in a VMWM is similar to the rat's behaviour in a real water maze (Jacobs et al, 1997; Jacobs, Thomas, Laurance and Nadel, 1998). Whilst there may be different behavioural demands involved in navigating in simulated non-immersive environments, the weight of evidence and opinion seem to endorse the advantages of using virtual reality to study spatial learning (Burgess & King, 2004).

Cheng (1986) and Gallistel (1990) suggested that learning about geometry operates independently of other types of spatial learning involving features. The first stage of the present research programme aimed to investigate this hypothesis by examining whether cue-competition effects occur between environmental structure and other spatial features that could potentially help to localize a goal in a VE. Finding a hidden goal in a fixed location relative to structures such as the boundary walls of an enclosure, constitutes geometric learning in accordance with Gallistel's (1990) definition. Determining a vector to an invisible goal using visible cues that are not adjacent to the goal is referred to as piloting. Vector information includes direction and distance knowledge, and therefore geometric relationships. Piloting to a target location could be based on the individual or collective properties of enclosure walls, or on the intrinsic geometric properties of an asymmetric landmark. If location learning based on the geometric properties of enclosure walls is found to block learning based on the geometric properties of a landmark then it would indicate that spatial learning using geometry is subject to the same error-correcting learning mechanisms as other forms of contingency learning. More generally, a blocking outcome would also undermine the incidental learning mechanisms specified by the theory that predicts that any cue added to an environment leads to an automatic updating of a cognitive map which is immune to cue competition.

2.2 Experiment 1

Cheng (1986) and Gallistel (1990) propose that learning about geometric relationships operates within a distinct module that is impervious to competition from other kinds of cue. An implication of this theory is that different sets of geometric cues will not compete with each other. Should different sets of geometric cues compete, the geometric module would be operating according to the same type of error-correcting mechanism that governs learning about other kinds of events. It seems implausible to maintain that a 'module' that processes geometry, and is immune to cue competition from other features, should also operate according to the same processes that govern cue competition when learning about other types of event.

To test this hypothesis, using a blocking design, Experiment 1 investigated cue competition between two sets of cues that individually provided participants with geometric properties that could be used to locate a goal: enclosure walls and an asymmetric landmark. Participants were asked to learn the location of a hidden goal by exploring a desktop VE initially using only the four surrounding walls of an irregularly shaped enclosure. The walls of an irregularly shaped enclosure can in principle provide unambiguous *shape* information that can be used to find a hidden goal location. In terms of Gallistel's (1990) definition, the properties of an irregularly shaped enclosure provide location information based on the position of the surface of each wall relative to the other walls of the enclosure. In the second phase of training an asymmetric landmark was introduced within the enclosure which provided similar kinds of geometric information. In the test, the extent of learning about the landmark alone was compared to that of a control group which had not had initial training with the enclosure. Failure to find evidence of cue competition between the enclosure and the landmark would provide support for the unique operation of a geometric module. Evidence for cue competition would indicate that learning about geometry operates in accordance with mechanisms that govern other types of contingency learning.

2.3 Design

In a variant of the standard blocking design (see Table 2.1 and Figure 2.1), participants in the experimental group learned to locate an invisible platform on the ground of a four-walled, irregular-shaped virtual enclosure. In phase 2, they continued to search for the invisible target (which remained in the same location within the enclosure as in phase 1) but a stable local landmark was added within the enclosure walls (see Figures 2.1 and 2.2). The landmark was an upright cross that was lighter on one side than the other and remained in a consistent spatial relationship to the platform and enclosure walls. In the test phase, the landmark and invisible platform maintained the same physical relationship to each other as in phase 2, but they were presented within a circular rather than irregular-shaped enclosure (Figure 2.1). A circular enclosure was chosen to ensure that the walls could not be used to locate the target location. The wall of a circular enclosure creates a uniform surface that is ambiguous in terms of the localization information it provides. Consequently, in the test, the enclosure shape could no longer be used as an aid to searching; only the landmark could accurately indicate the location of the platform.

The control group received the same phase 2 and test phase treatments as the experimental group, but in place of phase 1 training, they carried out an unrelated task. The first prediction consistent with a demonstration of cue competition is that in the test, when only the local landmark introduced in phase 2 was available to locate the goal, the experimental group should search less efficiently than the control group i.e. their search latencies would be longer.

The principal aim of Experiment 1 was to seek evidence of blocking of learning based on two sets of geometric cues. The walls conceivably provide more than one type of geometric cue. Considered in relationship to each other, the walls form an overall *shape* that could be used to find the goal. However, it is possible that learning in the irregular-shaped enclosure might not be based on overall shape. The enclosure had four walls of differing length, and goal-localization might therefore be achieved with reference to distinctive individual walls or corners. To investigate this possibility, for half of the participants the platform was located near the longest wall, while for the remaining participants it was near the shortest wall (see Figure 2.3). Equivalent performance in both platform locations would suggest that the overall geometric properties of the enclosure shape had been processed. Different blocking effects related to different goal locations would suggest the influence of local features in cue competition.

Group	Phase 1	Phase 2	Test
Experimental	Shape	Shape + Landmark	Landmark
Control	Irrelevant task	Shape + Landmark	Landmark

Table 2.1. The design for Experiment 1: a variant of the standard blocking design (Kamin, 1969)

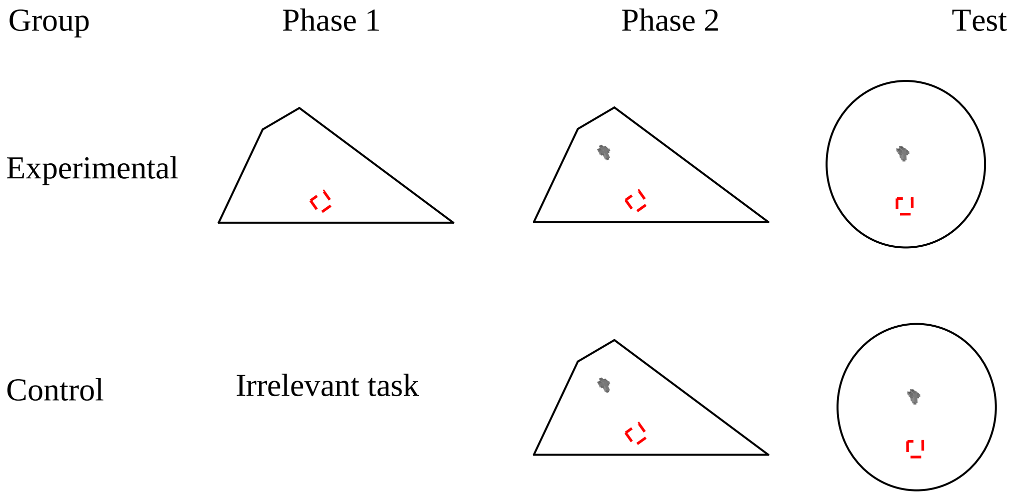

Figure 2.1. Experiment 1: Scale plan views of the enclosures used for each phase in both groups. The shape was an irregular four-sided enclosure. The landmark was a single upright grey cross with its lighter side facing the goal, an invisible platform (for illustration shown by a red dashed square). In the test, the landmark was presented facing the goal in a circular enclosure. The irrelevant task for the control group in place of phase 1 was exploration of a maze to give experience of moving around a VE but did not involve a search for a hidden platform (See Appendix Figure A.7.1).

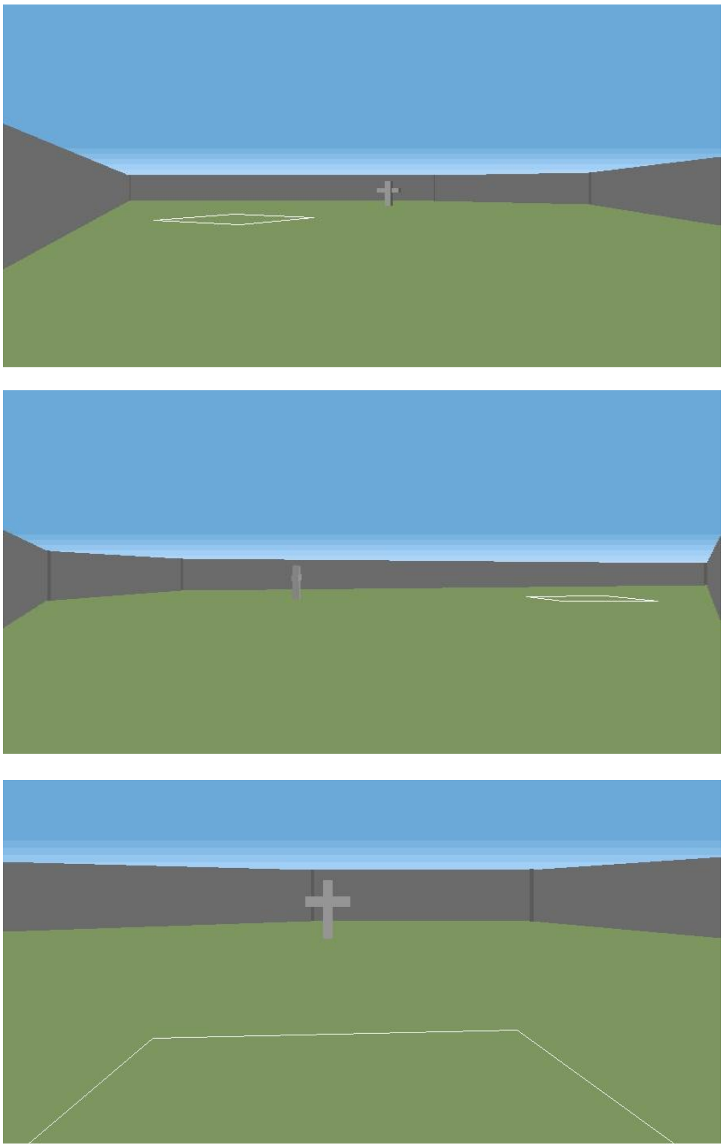

Figure 2.2. First person perspective views seen by participants during exploration of phase 2 VEs for Experiment 1. Upper two panels: from two different locations within the irregular shaped enclosure. Lower panel: the view seen whilst stood on the edge of the platform facing the cross with the shortest wall behind the cross. For illustration purposes, the location of the invisible platform is outlined in white.

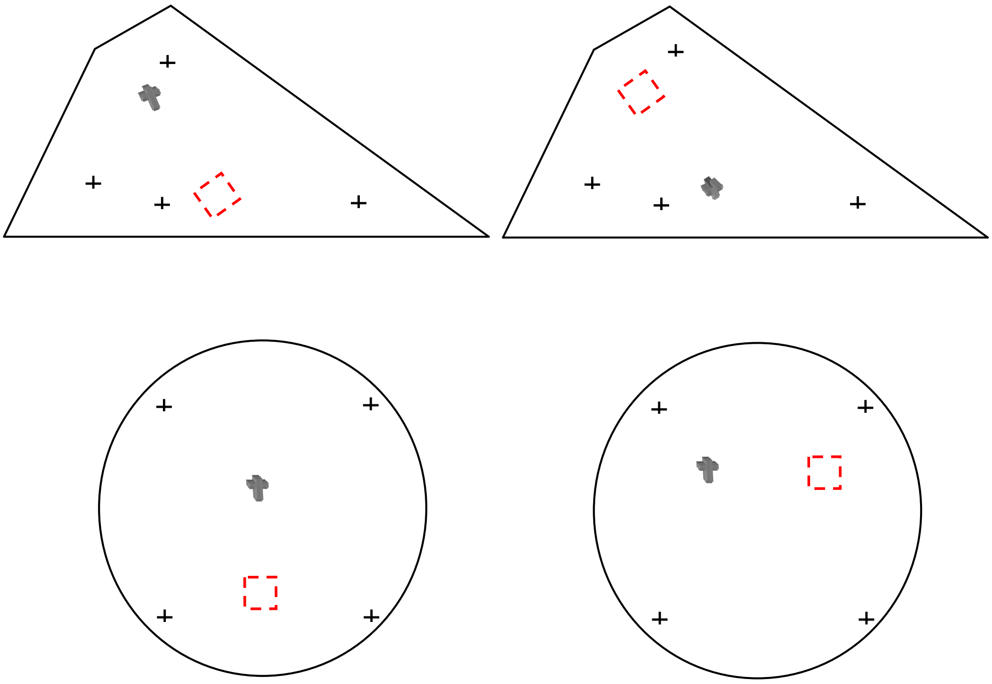

Figure 2.3. Scale plan views of the two versions of the phase 2 (upper panels) and test 1 (lower panels) enclosures showing the location of the single local landmark (shaded cross) that faced toward the invisible goal, and the four start positions indicated by the small crosses. For illustration purposes the hidden platform is indicated with a red dashed square.

2.4 Method

2.4.1 Participants.

Participants in all experiments in this thesis were undergraduates or postgraduates from the University of Hull. All took part either to obtain course credit or were compensated for their travel, and all had normal or corrected to normal vision.

In Experiment 1, 80 participants were randomly assigned to 2 groups. They had a mean age of 21.1 years (range: 18 to 42 years), and 36 were men (17 men served in the blocking group and 19 men in the control group). In all experiments there were equal numbers of participants in experimental and control groups.

2.4.2 Apparatus.

All VEs in this thesis were created using the Superscape Virtual Reality Toolkit, and were presented via an Intel Pentium computer with SVGA graphics, displayed on a 21-inch flat screen monitor. Rotation and translation movements were restricted to the horizontal plane, and were effected when participants pressed the arrow keys on the keyboard (↑ = move forward, ↓ = move backwards, ← = turn left, → = turn right). Two controls could be used simultaneously thus allowing participants to move forwards and rotate at the same time. Movement in all environments was programmed such that the equivalent of approximately 30 m could be traversed in 12 s, and a 360° rotation took 8 s. Auditory feedback was provided through external amplified speakers.

The main experimental VE was an enclosure which, in plan view, comprised a four-sided irregular polygon. Assuming average eye-level to be 1.65 m, the approximate subjective lengths of the enclosure walls translate to 63, 51, 29, and 13 m (see Figures 2.1 to 2.3), and all were 3m high. The walls were light-grey with wall-height, dark grey, posts at the corners; the ground was green, and the sky was blue. A similarly-coloured circular enclosure with approximately the same floor area was also employed.

On the ground within each enclosure was a flat, horizontal, 4.4 m square invisible platform. When a participant ‘moved onto’ the platform, a brief, loud, train of bleeps provided auditory feedback. In the irregular-shaped enclosure, for half of the participants the platform was located 4 m in from the mid-point of the longest wall, while for the remaining participants it was 4 m in from the mid-point of the shortest wall (Figure 2.3). In phase 2 and the test, a single local landmark comprised a 3D, upright, grey cross, 2.1 m high and 1.6 m wide. One face of the cross was light grey and the other was dark grey; the light side of the cross faced the invisible platform at a distance of 12 m from its nearest edge. In the test, conducted in the circular enclosure, for half the participants the landmark was situated near the centre, and for the remaining participants it was off centre (Figure 2.3). For all participants, the platform was located in the same physical relationship to the landmark (i.e., light side of the landmark facing the goal) whenever it was present.

A maze of grey corridors, approximately 11 m high and 9.5 m wide, was employed for control participants to explore in place of phase 1 training, to equate the experience of the groups in moving around VEs. When selected correctly, a series of six 90° left and right turns brought the participant to a visible target, an animated character (see Appendix Figure A.7.1).

2.4.3 Procedure.

Participants in all experiments were seated approximately .5 m from the centre of the computer screen. In this and all subsequent experiments, in a preliminary training phase prior to phase 1, all participants spent 3 minutes exploring a square practice VE that contained an invisible platform to adapt to ‘moving’ using the keyboard keys, and to experience the train of bleeps that signalled they were located on the invisible platform. Participants were encouraged to make turns whilst maintaining forward motion to simulate how they might explore in the real world.

Participants in all experiments were given identical verbal instructions. They were instructed that the task was to locate a hidden platform located on the floor which would emit a sound when located. At this stage the experimenter demonstrated how to effect movement and find the hidden platform in a pretraining VE. Following the preliminary training phase as described below, participants were given verbal instructions regarding the experimental task. They were advised that the task was to locate a hidden platform as quickly as possible over a series of trials and that they would commence each trial facing the wall of the enclosure. They were told that each trial would commence with the experimenter saying ‘go’ at which time they should turn away from the wall and start searching for the platform and locate it as efficiently as possible. They were advised to stop moving when they found the hidden platform (indicated by a distinctive train of beeps) and then to rotate through 360° as this could aid platform discovery on subsequent trials. Each trial started from 1 of 4 pseudo-randomly determined start-points in the enclosure which were selected by the experimenter using an assigned key on a separate keyboard; the same start location was not used on immediately successive trials (see Figure 2.3). Search latencies were recorded using a handheld stopwatch from participants' first keyboard press that initiated movement to the onset of the auditory feedback (the train of bleeps) that indicated that they had found the platform. Following rotation at the end of each trial, the VE was reset by the experimenter pressing an F-key on a separate keyboard to select a new start location and a new trial commenced. The inter-trial interval was approximately two seconds during which time the participants saw a grey screen. Transition between phases was effected by the experimenter selecting the relevant VE via a File drop-down menu. Participants were never informed whether the platform would move or stay in the same location or that cues within the environment would change.

In this and all subsequent experiments, in a preliminary training phase prior to phase 1, all participants spent 3 minutes exploring a 23m square practice VE that contained only an invisible platform to adapt to 'moving' using the keyboard keys, and to experience the train of bleeps that signalled they were located on the invisible platform. Participants were encouraged to make turns whilst maintaining forward motion to simulate how they might explore in the real world. When they 'moved' onto the platform the computer emitted a distinctive series of bleeps, at which point they were asked to rotate through 360°.

In the 8 trials of phase 1, experimental participants searched for the invisible platform using only the surrounding irregular-shaped enclosure walls, while control participants explored the unrelated maze of corridors. In the 8 trials of phase 2, both groups searched the irregular-shaped enclosure which also contained the fixed landmark (the cross). In the test, comprising 8 trials, the landmark and invisible platform were presented within a circular enclosure for all participants.

2.5 Results and discussion

An alpha level of .05 was adopted for all the analyses reported in this thesis. Also, for all analyses search latencies were capped at 180 s, and outliers were removed according to the following criterion: on a trial by trial basis, any individual score that was more than 2 standard deviations above the mean of the group to which it belonged was assigned the mean score for that group. In Experiment 1, this procedure resulted in reductions to outliers that represented 5% of the latency scores. Preliminary analyses found faster mean search latencies in men than women in some phases, but sex did not interact with group in any phase; as no predictions were made concerning sex, this factor was not included in the main analyses.

The data from the training phases are presented in the left panel of Figure 2.4. In phase 1, latencies to find the hidden platform in the experimental group reached asymptote after 4 trials. A one-way repeated-measures ANOVA found a significant main effect of trials, *F* (3, 98) = 25.3, *MSE* =1108, *p* < .001, η_p^2 = .39 [Greenhouse-Geisser correction]. The data from phase 2 (middle panel of Figure 2.4) were entered into a 2 x 8 mixed ANOVA, with group (experimental, control), and trials, as factors. Both main effects and the interaction were significant, *Fs* > 21.00, *MSEs* < 417 *p*s < .001, η_p^2 > .21; latencies were significantly faster in the experimental group on trials 1-3, and 5.

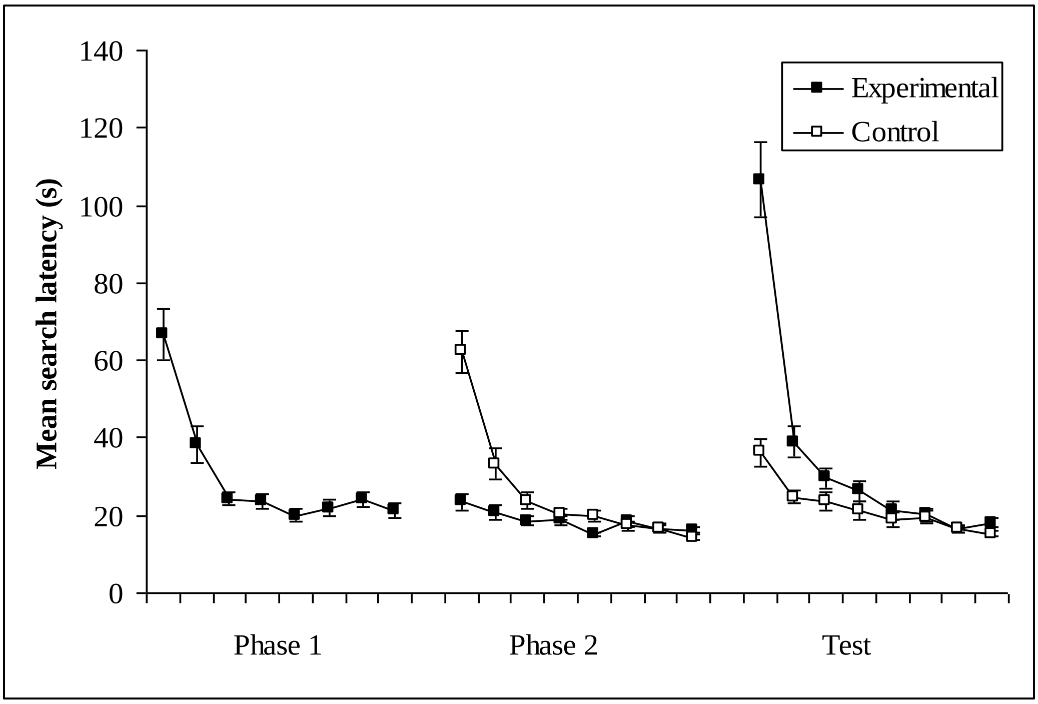

Figure 2.4. Experiment 1: mean search latencies for the 8 trials in each of the learning and test phases. Error bars represent one estimated standard error above and below the mean.

The latency data from the test are illustrated in the right panel of Figure 2.4. The experimental group was significantly slower to find the platform on the first test trial, independent-*t* (61) = 6.91, *p* < .001, confirming a blocking effect. A 2 x 2 between-participant ANOVA on the first test trial, with factors of group and platform location, found a main effect of group *F* (3, 76) = 51.6, *MSE* =1918, $p < .001$, $\eta_p^2 = .41$, and a borderline effect of platform location *F* (3, 76) = 3.91, *MSE* =1918, $p = .052$, $\eta_p^2 = .05$. There was also a significant Group x Platform Location interaction, *F* (3, 76) = 4.90, *MSE* =1918, $p < .05$, $\eta_p^2 = .06$. The borderline effect of platform location reflected longer search latencies when the platform had been located close to the short wall (*M* = 81) rather than to the long wall (*M* = 62) during training. The Group x Platform Location interaction suggested that the effect of blocking was greater when the platform had been located close to the short wall during training (*M* = 35 and 127 s for control and experimental groups respectively) than when it had been located close to the long wall during training (*M* = 37 and 86 s respectively).

The suggestion of a geometric module (Cheng, 1986; Gallistel, 1990) implies that cue competition should not occur when learning about different sets of geometric relationships. The main finding from Experiment 1, however, was that an initial phase of learning to locate a goal in an irregular-shaped enclosure blocked learning about the spatial relationship between a subsequently added local landmark and the goal location. This outcome supports the hypothesis that cue-competition effects can operate during spatial learning based on different sets of geometric properties. It provides initial evidence that spatial learning based on geometry operates in accordance with the same error-correcting learning mechanisms that govern other forms of contingency learning.

The second interesting finding was that blocking of the local cue was greater if the invisible target had been located close to the short rather than the long wall. If blocking participants had learned about the overall shape of the enclosure during phase

1, such a difference would not be anticipated in the test. Shape learning should facilitate the calculation of co-ordinates from each of the boundary walls or corners (e.g. Hartley, Trinkler & Burgess, 1994), i.e., with reference to the shape as a unitary global cue. It is possible therefore that in Experiment 1 participants were not using the shape as a whole to determine the location of the platform. Data were not formally collected regarding the specific strategies adopted by participants, however, casual comments made following completion of the task indicated that participants may have had a preference for using features such as a specific wall or corners to aid their search. Consistent with this speculation, Wilson and Alexander (2008) used the same irregular shaped environment as in Experiment 1 and conducted structured assessments of the strategies used by participants. Their formal assessment of search strategies revealed that only 8% of participants reported using the overall shape to locate the platform whereas 83% reported using a single wall or corner. Furthermore only 20% of participants were able to draw an accurate plan of the enclosure, although 67% could select the correct prepared plan-view shape when it was presented alongside distracter shapes.

Experiment 1 provided evidence for cue competition between an enclosure of irregular shape and a local landmark. Although the enclosure walls formed an angular shape this does not necessarily imply that participants used overall shape to locate the platform. Participants’ casual comments suggested that they more often used subsets of the walls and the angles formed by walls at corners to judge the location of the target. The variability of the blocking effect depending on proximity of the goal to a particular wall also suggests participants used features such as corners and wall length rather than overall shape. When participants were initially trained with the platform close to the short wall, learning about the subsequently added local cue was poorer than when initial training had been close to the long wall. This may be because the short wall location provided more accurate localization information than the long wall and less attention was paid to the cue added in phase 2. Although the blocking effect was also found in relation to the long wall location, more was learned about the added cue compared to the short wall group. Participants in Experiment 1 were never able to see a representation of the irregular enclosure in its entirety, so perhaps it is understandable that they may have tended to focus on individual elements that were most readily available to aid target localization.

The aim of Experiment 1 was to establish whether cue competition occurs when geometric information is used as a cue to goal localization. The finding of blocking using an irregular shaped enclosure is consistent with the associative account of spatial learning and provides no support for the proposal of a geometric module which operates independently of a cue competition mechanism. As the walls of the enclosure were of different length, the overall shape of the enclosure could provide an unambiguous cue to find the platform. However, there was no viewpoint from which the overall shape of the enclosure could be perceived and it is probable that individual elements of the enclosure such as corners or walls were used to locate the invisible goal. The self-reports of participants supported the possibility that the enclosure could be used in different ways to find the platform.

Both animal (Pearce et al 2001, 2006) and human (Redhead & Hamilton, 2007) spatial cue competition experiments raise the possibility that enclosure shape processing might involve special geometric properties that are immune to cue competition. However, Experiment 1 found no support for this proposal. Unfortunately, the design of this experiment limits interpretation of the outcome with respect to overall shape-learning. It seems likely that individual walls or corners were used to locate the goal in preference to overall shape. Research with rodents points to a similar conclusion (Pearce et al, 2004). Therefore, there is presently no unequivocal evidence on whether location learning based on shape occurs at all, or is immune to cue competition if it does occur. A major methodological advance in understanding human cue competition effects in spatial learning would be to take steps that ensure that shape properties are required for goal localization.

CHAPTER 3

FAILURE TO FIND CUE COMPETITION BETWEEN LARGE SCALE SHAPES

3.1 Experiment 2

Although blocking was found in Experiment 1, it was not possible to resolve whether participants perceived and processed the shape of the enclosure as a whole. Potentially, only elements of the enclosure shape had been learned about, rather than the overall Euclidean shape. An interpretation of the blocking effect in Experiment 1 as evidence that undermines the geometric module hypothesis is therefore incomplete.

Animals are able to make discriminations between shapes by detecting only small differences in features of discriminative stimuli; in the case of location learning based on geometric cues, such features are presumably provided by room corners and wall length. Goals can be found without the need to process overall shape. Humans can make similar discriminations between local spatial features (Experiment 1; Wilson and Alexander, 2008), but the ability to process and conceptualise overall environmental *shape* could well be a uniquely human ability. However, in everyday life, people are rarely called upon to use overall environmental shape to locate a goal. Access to plan views of rooms is not routinely available, and people rarely have the opportunity to view environmental shape from a distance. It is possible, therefore, that location learning based on large scale environmental shape is poorly developed in most people, and local features are the preferred spatial cues for locating a goal. Thus, there is no evidence that directly bears on whether humans can use overall environmental shape to locate a goal, and if they can, whether shape processing is also subject to the same sort of learning mechanisms as other kinds of stimuli and events. The remaining experiments in this thesis are directed to this important issue.

To perceive a shape as a whole, it might be necessary to be able to view it from a distance so that all of its properties can be viewed simultaneously. In Experiment 1, within the confined space of the enclosure, there were no views that involved all walls. To address these issues, the remaining experiments in this thesis were conducted with a procedure that ensured that whole shapes were perceived from many angles.

The lack of experimental evidence regarding whether location learning based on one shape can interact with location learning based on another shape is perhaps due to the problem of how to make two large-scale cues concurrently predict a location while both are simultaneously in view. For two shapes to simultaneously indicate the location of a hidden goal, they should preferably be presented in compound and close to each other so that their surfaces overlap. This will ensure that both shapes are perceived equally well when the hidden location is found. However, if two large three dimensional shapes are compounded, then some properties of the original shapes are lost because a new shape will be created (Figure 3.1)

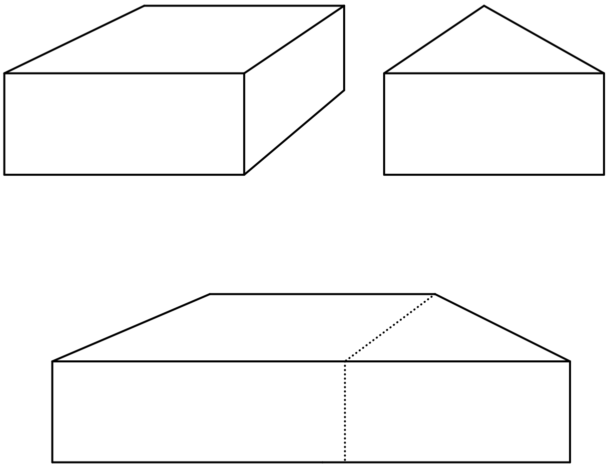

Figure 3.1. The upper two 3D shapes have independent properties when presented individually. When compounded in the lower frame they lose some of their original properties and a new overall shape is created.

To address this problem in the current experiments, a procedure was adopted in which large horizontal 2D shapes on the ground of a VE could overlap, and indicate a target location either independently or simultaneously. In relation to the perspective of the explorer, one shape was approximately equivalent in area to the floor of a very large room, and the other was approximately equivalent in area to the floor of a small room. Thus, these 2-D shapes can be conceptualised as equivalent to the floor-areas of walled-enclosures. The advantage of adopting these cue types and procedure is that one shape can be superimposed onto another shape whilst maintaining the intrinsic properties of each original shape. During exploration participants were therefore able to perceive the entire outline of the shapes both as individual entities and in compound.

3.1.1 Design

In Experiment 2, a variant of Kamin's (1969) standard blocking design using shapes as the target cues was employed (see Table 3.1). The task, as in Experiment 1 was to find an invisible goal location. To ensure that the search for the platform remained in the general location of the 2D target stimuli, a very wide circular enclosure surrounded the search area. This wall could not act as a spatial cue to localization of either the shapes or the goal.

Group	Phase 1	Phase 2	Test
Experimental	A+	AB+, YZ	B+, Y
Control	C+	AB+, YZ	B+, Y

Table 3.1 The design of Experiment 2. Room-sized shapes-A and -B were a large black triangle and smaller white octagonal (counterbalanced); shape-C in the control groups was either a large, black, T-shape, or a small, white, T-shape (to conform to the sizes of A and B in the experimental groups). Shapes Y and Z were one black, and one white, smaller auxiliary shapes. + indicates that the platform was located a short distance from the shape or shape configuration.

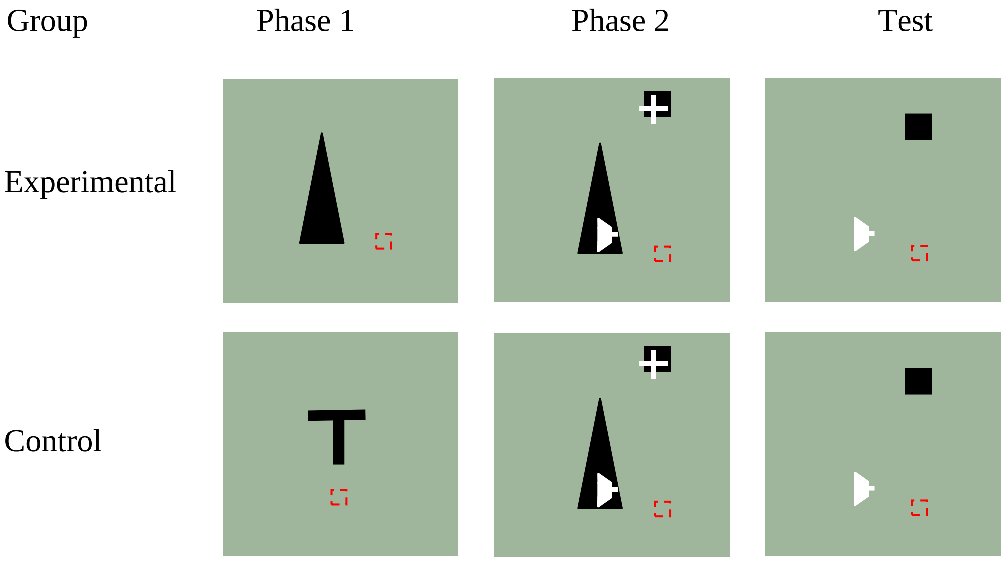

Figure 3.2. Scale plan layouts of the stimuli used in Experiment 2. For illustration purposes the platform location is indicated by a red dashed square. See Appendix Figure A.7.2 for an illustration of the counterbalanced stimuli.

In phase 1, the platform was consistently situated a short distance from shape-A, such that the properties of the shape could be used to determine a vector to the platform. The intention behind spatially separating the platform and shape was to ensure that participants had to use the geometric properties of the entire shape to determine the location of the platform. Participants were required to pilot, where piloting is defined as using visible cues to locate a distal invisible target location. An analysis of what was learned about the shapes in phase 1 was facilitated by using both a large and small version of shape-A in a counterbalanced arrangement. If locating the goal was based on a random search pattern directed to the general area of the shapes then latencies to find the platform relative to the large shape would take longer than to the small shape. No difference in search latencies according to shape size would indicate that goal-localization was based on the geometric properties of each shape. In phase 2, a second shape, B, was compounded with shape-A, and the platform remained in the same relative location with respect to shape-A. The control group received the same training as the experimental group, except that in phase 1 they learned to find the platform based on piloting using shape-C, which was not related to shapes A and B introduced in phase 2, the compounding stage. Shapes A and B were different shades (black and white) so that both would be obvious when they were compounded; therefore, two additional colour-control cues (YZ) were employed in phase 2 and these also formed a compound of the shades used for the target cues. Shapes Y and Z differed geometrically from shapes A and B and did not maintain a consistent relationship to the target location. Thus, learning in phase 2 could not be based on approach to blackness or whiteness or a black and white compound; only the specific shapes defined the platform location.

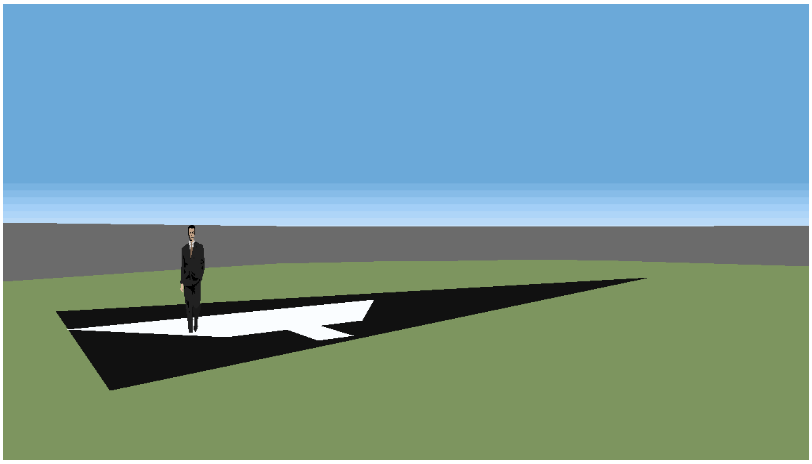

Figure 3.3. First-person perspective view from the platform location of the VE used in phase 2 showing the compounding of stimuli A and B. The human figure illustrates the relative size of the environment with respect to the participant’s view, assuming eye-level to be 1.65 m, but the figure was never presented in the experiment.

In a test phase, both groups were required to find the platform with only shape-B (and a control cue, X) available. As experience with shape-B was equated between groups in phase 2, slower search latencies by experimental compared to control participants would be evidence of blocking of learning about shape-B by prior training with shape-A. This would indicate that spatial learning using shape conforms to associative learning principles. No difference between groups would be consistent with the suggestion that target location learning based on shape is not subject to associative learning effects and that shape is processed in a specialised geometric module (Cheng, 1986; Gallistel, 1990).

3.1.2 Method

3.1.2.1 Participants

There were 48 participants; three participants were replaced as they showed no evidence of learning in at least one of the training phases. Those who participated had a mean age of 19.6 years (range: 18-31 years), and 24 were men (12 men served in the experimental group, and 11 men in the control group).

3.1.2.2 Apparatus

The search area was defined by a wide, approximately circular, grey wall, and the floor of this area was uniform green. The experimental cues were two-dimensional shapes presented horizontally at floor level, and were shaded either black or white (see Figures 3.2 and 3.3). Four shapes were used as experimental stimuli: a black T-shape, a white T-shape, a black isosceles triangle and a white irregular octagon (hereafter referred to as the ‘irregular-shape’). The area of the triangle was approximately 6.5 times larger than the area of the irregular shape. Two other shapes, a white cross and a black square served as colour-controls. Assuming average eye level to be ≈ 1.65 cm, the subjective dimensions of the environment were as follows: the diameter of the enclosure was 35 m with 2 m high walls, the distance from the base to the apex of the triangle was 16 m, and the triangle’s base was 7 m wide, the stem of the black T-shape was 8 m with a 9.5 m wide bar, the stem of the white T-shape was 4.5 m with a 4.5 m wide bar, the irregular shape was 5.5 x 3 m between its most distant edges. The invisible platform was a 2.2 m-sided square located approximately 8 m from the target shapes (see Figure

3.2 for platform location). The colour-control cues were a black 4 m sided square, and a white cross comprising two 4.5 m bars. An additional ‘pretraining’ environment comprised a square enclosure with walls 24 x 2.9 m, which was empty apart from a centrally located 4.4 x 4.4 m invisible platform. Movement was set to a fast walking pace so that the 36m enclosure could be traversed in 23 s; and a 360° rotation was effected in 6.3 s.

3.1.2.3 Procedure.

The experiment comprised four phases: Preliminary training, to practice movement; phase 1, in which a single shape, A or C, for experimental and control groups respectively, predicted the location of the invisible platform; phase 2, in which for both groups shape-B, was compounded with shape-A, and the compound AB could be used to locate the platform (which remained in the same relative location to shape-A as for the Experimental group in phase 1); Test phase, in which only shape-B and a control shape-X was available.

All participants were given preliminary training in a practice environment as outlined in Experiment 1. In phase 1, experimental participants were asked to find the invisible platform which was located in a fixed place external to, but nearby, shape-A on the enclosure floor (see top left panel of Figure 3.2); for half the experimental participants shape-A was the triangle, and for the remainder it was the irregular-shape. For half of the control participants shape-C was the black T-shape (see bottom left panel of Figure 3.2) which served to indicate the platform location, whereas for the remainder the smaller white T-shape served in this role (see Appendix Figure A.7.2). On 16 trials, participants found the invisible platform, starting from one of four possible start locations (all evenly spaced and approximately halfway between the centre of the circular enclosure and its perimeter), which were pseudo-randomly selected on each trial with the constraint that no location was selected on two successive occasions. Search latency was recorded from the moment the participant pressed the key to initiate movement until the onset of the sound that indicated the platform had been located. Participants were encouraged to rotate their view through 360° when they moved onto the platform.

In phase 2, for all participants the platform was located a fixed distance from a compound of shape-A and shape-B (i.e., the triangle and the irregular-shape, see centre panels of Figure 3.2), maintaining the vector between shape-A and the platform that was present in phase 1 for the experimental group. A second ‘colour-control’ compound, comprising a white cross (4.6 x 4.6 m) slightly offset from the centre of a black square (4.1 x 4.1 m), was added in phase 2. Phase 2 comprised 12 trials from the four varying start locations used in phase 1, with a new arrangement of the target compound (AB) and goals and the colour-control compound locations on each block of four trials (see Appendix Figure A.7.7). The new arrangement of colour-control compounds was selected by a mouse-click by the experimenter on the enclosure wall which loaded the next arrangement of cues on trials 5 and 9. This was to ensure that the non-target compound bore no consistent relationship to the platform location. The order of the changing arrangements was counterbalanced between participants in each group. The addition of the colour-control compound ensured that the platform could not be found simply by approaching blackness, whiteness, or a colour compound; thus, the geometric properties of the target shapes remained the only consistent predictors to aid goal localization.

In the test, shape-B was presented, and the invisible platform maintained the same relationship to shape-B as it had during phase 2. One of the elements that formed the colour-control compound in phase 2 was also presented in the test as a distractor (see right panels of Figure 3.2). Eight test trials were presented, from the varying start locations used in phases 1 and 2, counterbalanced across participants within each group.

3.1.3 Results and discussion

The application of the exclusion criteria detailed in section 2.5 resulted in reductions to outliers that represented 5.4 % of the latency scores.

In all remaining experiments in this series, preliminary analyses of variance (ANOVA) were carried out on both learning phases and the first trial of the test phase, with group, sex, trials, and stimulus-counterbalancing as factors in all cases. These analyses found a significant main effect of sex in 9 analyses out of 21 (7 experiments with 3 phases for analyses in each); in all cases the direction was faster search by men. Interactions involving sex were few (3 of the analyses), and none reflected on the experimental hypotheses. As no hypotheses about sex were formulated, sex was not included as a factor in any main analysis. No interactions that involved stimulus counterbalancing (in 3 of the 21 analyses) reflected on the experimental hypotheses. Therefore, stimulus counterbalancing was not included in any main analyses.

The interpretation of what was learned about the shapes in the present series is facilitated by analysis of whether larger and smaller shapes served equally well in guiding participants to the platform. Therefore, prior to the main analyses in each experiment, separate assessment was made of learning based on the larger and smaller shapes in phase 1.

A mixed 2 x 16 ANOVA analysis of the phase 1 stimulus data with stimulus (larger or smaller stimulus from both groups combined) as the between-participant factor, and trials as the repeated-measures factor, found no main effect of stimulus, F (1, 46) = .367, MSE = 984, $p > .05$, $\eta_p^2 = .008$, and no interaction with this factor, F (3, 157) = .784, MSE = 2021, $p > .05$, $\eta_p^2 = .017$ [Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, F (1, 22) = 1.25, MSE = 849, $p > .05$, $\eta_p^2 = .05$, and no interaction with this factor, F (4, 84) = 1.51, MSE = 1519, $p > .05$, $\eta_p^2 = .064$ [Greenhouse-Geisser correction applied]. Trial by trial independent t-test analyses on both the above data sets, uncorrected for multiple comparisons, found no significant differences on any trial (ts < 2, ps > .07).

The left panel of Figure 3.4 shows that the control group were slower to find the platform on trial 1 of phase 1 but this difference did not reach statistical significance, *t*(44) = 1.68, *p* >.05. Both groups learned at similar rates in subsequent trials and achieved asymptotic responding over the final seven trials (with a mean search latency of approximately 19 s). A 2 x 16 mixed ANOVA, with group as the between-participant factor, and trials as the within-participant factor, found a main effect of trials, *F* (4, 162) = 37.41, *MSE* = 1904, *p* < .001, η_p^2 = .45 [Greenhouse-Geisser correction applied]. No other effects or interactions were significant. The main effect of trial reflects longer mean search latencies on trial 1 compared to subsequent trials.

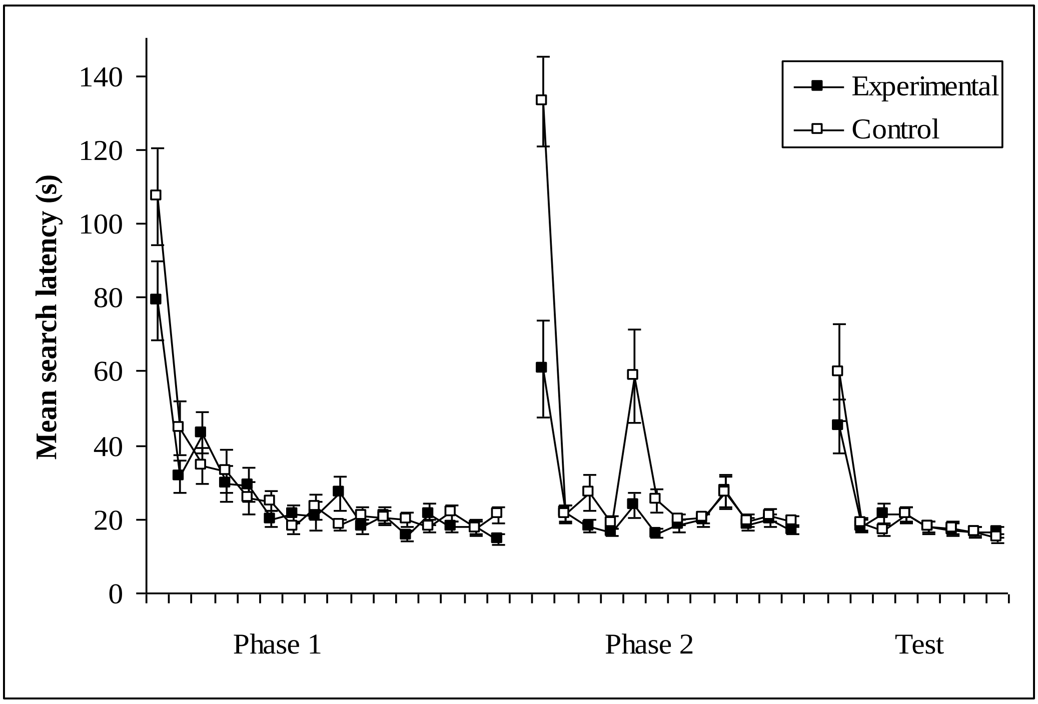

Figure 3.4. Experiment 2: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 3.4. A 2 group x 12 trials mixed ANOVA on these latency scores found main effects of group, F (1, 46) = 25.98, *MSE* = 686, p < .001, η_p^2 = .36 and trials, F (2, 103) = 40.15, *MSE* = 2919, *p* < .001, η_p^2 = .47, and a Group x Trials interaction, F (2, 103) = 9.37, *MSE* = 2920, *p* < .001, η_p^2 = .17 [Greenhouse-Geisser corrections applied]. The main effect of group reflects longer overall latencies in the control group than the experimental group, and the main effect of trials reflects the reduction in mean latencies as training progressed. The Group x Trials interaction reflects significantly longer latencies between groups on trials 1, *t* (46) = 4.04, *SE* = 17.9, *p* < .001 and 5, *t* (46) = 2.67, *p* < .05 but no difference on trial 12, *t* (46) = 1.17, *p* > .05. The difference on trial 5 corresponds with the rearrangement of cues that occurred after every block of four trials.

Mean latencies to find the platform in the test are presented in the right panel of Figure 3.4. Although the control group was slower on the first trial of the test, this difference failed to reach statistical significance, *t*(36) = .97, *p* > .05. A 2 group x 8 trials mixed ANOVA on the data from all 8 trials found a main effect of trials, *F* (1, 64) = 18.18, *MSE* = 1998, *p* < .001, η_p^2 = .28, [Greenhouse-Geisser correction applied]. No other effects or interactions were significant. The main effect of trials reflected the reduction in search latencies as the test progressed.

Both groups learned with similar efficiency to locate the platform based on the shapes employed in phase 1. At the beginning of phase 2 the experimental group was significantly faster than the control group who had seen the compounded target shapes for the first time on trial 1 of this phase. Interestingly on this trial, the control group performed even less well than they did on the first trial of phase 1 (133s and 107s respectively) suggesting that the experience of finding the platform in phase 1 did not help them in phase 2. There are several strategies they may have adopted in phase 2: Firstly, on noticing the new configuration of cues they could have treated the trial as a completely new task and searched randomly. Secondly, they might have concentrated their search on the cue that most closely resembled the T shape in phase 1, in this case the white cross in the colour-control compound. Thirdly, because the platform was at a fixed distance from shape-A in phase 1, a similar strategy based on search at a fixed distance from available cues could have been transferred to phase 2. It seems unlikely that the search was purely random as it would be expected that performance should be no worse than on the first trial of phase 1 as the total search area did not vary between phases. More plausibly, if time had been spent searching at incorrect locations close to the colour-control shape in preference to locations close to the target shape compound-AB then latencies would be longer. Similarly if a search strategy had been adopted that involved navigating to regions at a fixed distance from the compounded cues then latencies would also be expected to be longer. This is because it took longer to search around both the colour-control cue and the target compound cue-AB in phase 2 compared to search around a single T shaped cue in phase 1. The slower latencies by controls on trial 5 occurred as after every block of four trials in phase 2, the arrangement of the target compound shape and the colour-control compound shape changed. Even though the platform was always closest to the target compound it was also possible to learn the location with respect to both the target and the colour-control compound. On trial 5 the placement of the colour-control compound changed in relation to the platform and the deterioration in performance by controls indicates that some participants must have had at least partly relied on the colour-control compound for initial target localization. It is clear however, that as training progressed the discrepancies between groups disappeared and the control group learned that the compound of shapes A and B bore the only consistent relationship to the platform. Evidence of this is that on trial 9 when the arrangement of cues changed for the second time, and by the end of phase 2, both groups performed equally well.

In the test, the groups did not differ in their mean latency to find the platform at any stage, suggesting that the initial training on shape-A in the experimental group did not compete with the added cue in phase 2. Although on the first test trial the control group were slower than the experimental group, i.e. in the direction of facilitation, this difference did not reach significance. Therefore the outcome of the test phase is consistent with the suggestion that overall shape is processed in a dedicated geometric module that is immune to cue competition.

Experiment 2 also provided important evidence on an aspect of how participants used the shapes to locate the platform. The reduction in latencies as training progressed in each phase illustrates that search was not random; however, it is conceivable that search was based on an essentially random pattern of movement directed towards the general regions at a certain distance from the experimental shapes, rather than based on specific knowledge of the geometric properties of these shapes. For example the platform could be found by following a path moving clockwise or anti-clockwise at a fixed distance from the perimeter of the shapes. This type of search pattern or strategy would eventually result in finding the platform irrespective of any specific knowledge of the properties of the shape relative to the platform location. In the analyses of phase 1 latencies to locate the platform, no differences were found between latencies based on larger and smaller shapes. Crucially, no differences were found between latencies based on the triangle and irregular-shape that served as shapes-A and –B (counterbalanced) for participants in the experimental group. The area of the triangle was 6.5 times greater than that of the irregular-shape, and if search had been random, latencies to find the platform using only the triangle would have been much longer than using only the irregular shape. For example, circumnavigating the triangle perimeter took approximately 30 s compared to 10 s for the irregular shape. At the very least, these data confirm the casual observations that, following the initial trial, participants searched close to a particular vertex of the shapes rather than completing a random exploration of the entire shape. As learning progressed they approached a specific point directly from each of the random start locations. These data support the hypothesis that participants were using overall geometric properties of the shapes, rather than simply identifying shapes and searching randomly in their vicinity. Preliminary analyses in the remaining experiments in this series found outcomes consistent with this interpretation.

3.2 Experiment 3

Although in Experiment 2 positioning the platform some distance from the shapes should ensure that search was based on piloting using the geometric properties of the shapes, this aspect to the procedure is unusual as most experiments on geometric learning have located the target close to the edge of a shape, usually within a shape delimited by walls, and have required direct approach. It is possible that piloting to the platform might be more difficult or engage different processes in comparison with direct approach when the target is situated within a shape. Furthermore, piloting might encourage initial learning about the non-target, colour-control cues, as seen in phase 2 for the control group in Experiment 2. Therefore, in Experiment 3 the procedure of Experiment 2 was replicated, but the platform was moved close to the edge of the shapes (see Table 3.2 and Figure 3.5). The hypothesis was that approach to a location more precisely defined by the target shape might be more sensitive to cue-interaction effects than piloting was in Experiment 2. The overall outline of the shapes could still be processed as participants had to navigate to them from distal starting points, from where the whole of the stimuli could be viewed.

3.2.1 Design

Group	Phase 1	Phase 2	Test
Experimental	A+	AB+, YZ	B+, Y
Control	C+	AB+, YZ	B+, Y

Table 3.2 The design of Experiment 3. The design and stimuli used were identical to Experiment 2, except that + indicates that the platform was located on the periphery of the shape or shape configuration rather than distally.

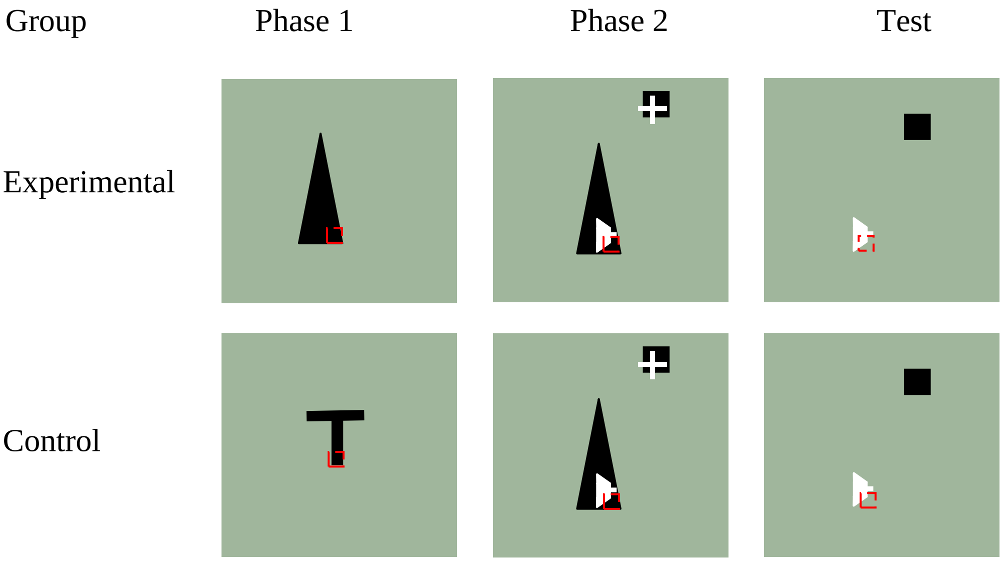

Figure 3.5. Scale plan layouts of the stimuli used in Experiment 3. The platform location was moved to the edge of the target shapes and is outlined by a red hashed square. See Appendix Figure A.7.2 for counterbalanced stimuli.

3.2.2 Method

3.2.2.1 Participants

These were 48 undergraduates of whom 24 were men; they had a mean age of 21.7 years (range: 18-45 years). They were randomly allocated to two groups with the constraint that equal numbers of men served in each group.

3.2.2.2 Apparatus

The apparatus was identical to that in Experiment 2, but the platform was moved to the edge of the shapes as indicated in Figure 3.5.

3.2.2.3 Procedure

The procedure was identical to that in Experiment 2. See Appendix Figure A.7.7 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

3.2.3 Results and discussion

Preliminary analyses with a mixed 2 x 16 ANOVA of the phase 1 stimulus data, with stimulus (larger or smaller stimulus from both groups combined) as the between-participant factor, and trials as the repeated-measures factor, found no main effect of stimulus, F (1, 46) = .053, MSE = 352, $p > .05$, $\eta_p^2 = .001$, and no interaction with this factor, F (2, 77) = .327, MSE = 2382, $p > .05$, $\eta_p^2 = .007$ [Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, *F* (1, 22) = .046, *MSE* = 370, $p > .05$, $\eta_p^2 = .002$, and no interaction with this factor, *F* (1, 30) = .7, *MSE* = 3205, $p > .05$, $\eta_p^2 = .031$ [Greenhouse-Geisser correction applied]. Trial by trial independent *t*-test analyses on both the above data sets, uncorrected for multiple comparisons, found no significant differences on any trial (*ts* < 2, *p*s > .05).

Mean latencies in phase 1 are illustrated in the left panel of Figure 3.6, from which it is apparent that the groups differed on the first trial when searching should have been essentially random for all participants, but thereafter groups searched at similar rates. Asymptotic responding was achieved in both groups over the final nine trials (with a mean search latency of approximately 16 s). A 2 x 16 mixed ANOVA, with group as the between-participant factor, and trial as the within-participant factor, found main effects of group, *F* (1, 46) = 5.72, *MSE* = 314, $p = .02$, $\eta_p^2 = .11$, and trials, *F* (2, 94) = 42.49, *MSE* = 1449, $p < .001$, $\eta_p^2 = .48$, and a Group x Trials interaction, *F* (2, 94) = 16.61, *MSE* = 1449, $p < .001$, $\eta_p^2 = .27$ [Greenhouse-Geisser correction applied]. Both the group effect and the interaction reflects faster responding by group control on the first trial (although this difference fell just short of statistical significance, $t(37) = 1.95$, $p = .059$) but no difference between groups thereafter.

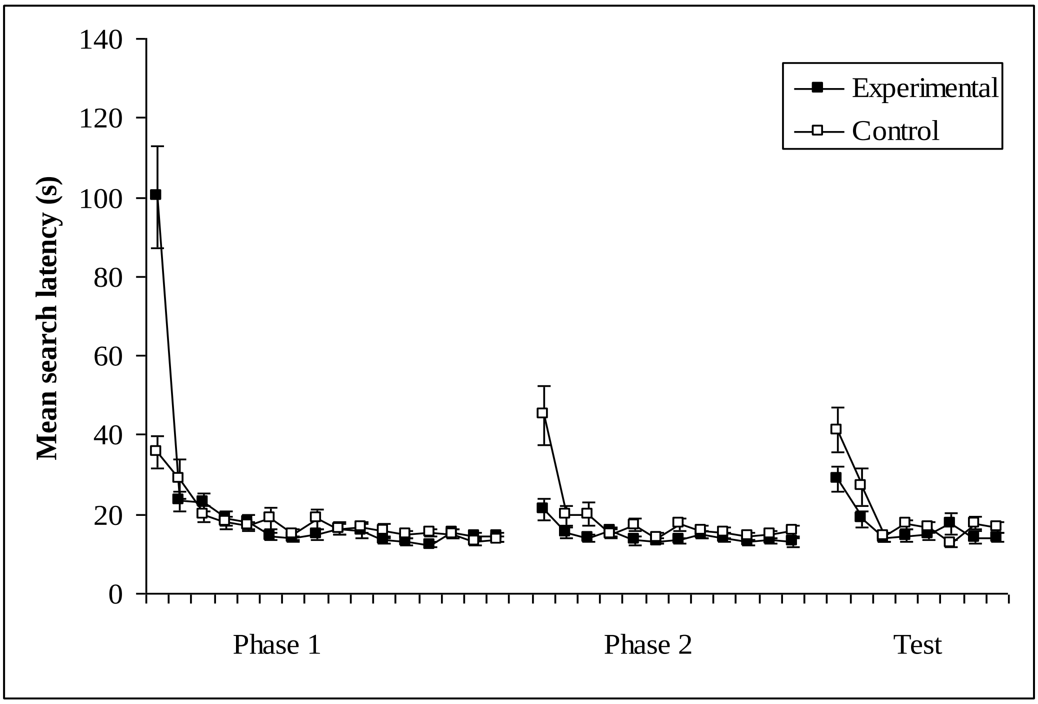

Figure 3.6: Experiment 3: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 3.6. A 2 group x 12 trials mixed ANOVA on these latency scores found main effects of group, *F* (1, 46) = 21.56, *MSE* = 119, $p < .001$, $\eta_p^2 = .32$, and trials, *F* (2, 113)

= 13.58, *MSE* = 444, $p < .001$, $\eta_p^2 = .23$, and a Group x Trials interaction, *F* (2, 113) = 5.01, *MSE* = 444, $p = .005$, $\eta_p^2 = .10$ [Greenhouse-Geisser corrections applied]. The main effect of group reflects longer overall latencies in group control than group experimental; the main effect of trials reflects a small reduction in mean latencies as training progressed, and the Group x Trials interaction reflects significantly faster search by group experimental on trials 1, $t(29) = 3.04$, $p < .01$, 5, $t(46) = 2.16$, p < .05 and 7, $t(46) = 2.49$, $p < .05$; no difference was apparent between groups on any other trial 12 (*ts* < 1.9, *p*s > .05). As in Experiment 2, the longer latencies in the control group on trial 5 (but not trial 7) correlates with the changing arrangement of the colour-control and target cues.

Mean latencies to find the platform in the test are presented in the right panel of Figure 3.6. An independent *t*-test on the first test trial found that the difference fell just short of statistical significance $t(46) = 1.95$, SE = 6.38, $p = .06$. A 2 group x 8 trials mixed ANOVA on the data from all 8 trials found main effects of group, *F* (1, 46) = 5.68, *MSE* = 187, $p = .02$, $\eta_p^2 = .11$, and trials, *F* (3, 144) = 18.31, *MSE* = 297, $p < .001$, $\eta_p^2 = .29$, [Greenhouse-Geisser correction applied]. The Group x Trials interaction was not significant, but had a borderline significance value, *F* (3, 144) = 2.51, *MSE* = 297, $p = .06$. The main effect of group reflects faster platform location overall in group experimental (*M* = 17 s) than group control (*M* = 21 s).

The principal finding from Experiment 3 was that, as in Experiment 2, blocking of location learning between shapes did not occur. This outcome is consistent with predictions based on the hypothesis that shape processing is immune to cue competition.

However, the group main effect in the analysis of all 8 test trials together is consistent with facilitation of learning: that is, more efficient learning about shape-B as a location indicator in participants for whom shape-A had been pretrained in phase 1. This direction of the effect conforms to that found with rats by Pearce et al. (2001; Experiment 5) using a conceptually similar design. However, on the first test trial where cue-interaction effects were predicted to be greatest, the group difference fell short of statistical significance. Therefore, the most conservative interpretation of the outcome of the test is that it provides a sound demonstration that blocking did not occur, rather than providing evidence for facilitation of learning. Moving the platform close to the periphery of the shapes resulted in a more even rate of learning than in Experiment 2 although learning in the control group was again disrupted on trial 5 when the arrangement of cues changed. Throughout the experiment learning progressed extremely rapidly in all phases, suggesting that most participants were able to learn the location of the platform after just one trial. Perhaps this is not altogether surprising as the stimuli were not complex, particularly in phase 1 with just a single cue available to indicate the target location. The speed with which participants could learn in phase 2 was a little more surprising given the increase in number of shapes presented.

An unanticipated feature of Experiment 3 was that the control group was very much faster than the experimental group to find the platform on trial 1 of phase 1 (although this fell just short of statistical significance). On this first trial, none of the participants had prior knowledge of any aspect of the VE, so searching was anticipated to be random and equivalent in both groups. Casual observation suggested that when experimental participants searched their cue (the triangle or irregular-octagon) they initially approached the target from a random direction; however, when control participants searched their cue (the large or small T-shape) they initially followed the apparent ‘path’ formed by the T, which led them directly to the platform situated at the base of the T-shape (cf. Experiment 5). This different search strategy in phase 1 does not compromise interpretation of the test results: control participants in related blocking designs commonly receive either, no phase 1 treatment, or, learning experiences in phase 1 that are irrelevant to phase 2 learning. Furthermore, in Experiment 2 in which the only procedural difference from Experiment 3 was that the platform was a short distance from the target shapes, following the T ‘path’ did not lead to goal discovery in phase 1. Even though initial mean latencies were similar between groups in phase 1 of Experiment 2, nonetheless the same direction of test outcome was found.

Experiment 3 demonstrated a further clear failure to find blocking of location learning between two large-scale shapes. As in Experiment 2, this outcome is consistent with the proposal that shape location learning is processed within a dedicated geometric module that is immune to cue competition. In both Experiments 2 and 3, the rate of learning in the training phases was very rapid and approximated one-trial learning. This suggests that participants may have adopted a strategy that supplemented location learning based purely on spatial relationships. Human contingency learning studies have found that people sometimes learn about cues and outcomes using rule-based rather than associative processes (Shanks, 2007). In the context of location learning a rule-based approach could be equivalent to a self-statement such as “the target is at the bottom-right vertex of the triangle”. Thus it is feasible that rational learning processes may have been engaged in Experiments 2 and 3 at the expense of associative learning mechanisms that would otherwise lead to competition between cues. This hypothesis and subsequent modifications were tested in Experiments, 4, 5 and 6.

CHAPTER 4

INCREASING TASK DEMANDS LEADS TO BLOCKING

4.1 Experiment 4

The approximation to one-trial learning apparent in both training phases of Experiment 3 is consistent with some kind of rational knowledge or hypothesis about how to find the platform location. The ease with which the goal location could be identified, based on just one or two large shapes, might have encouraged a learning strategy in which spatial knowledge was supplemented by verbal or propositional encoding. In human contingency learning experiments, cue-competition effects are influenced by task demands, and outcomes are more likely to be consistent with associative learning predictions when many rather than few cues are employed (see De Houwer & Beckers, 2002). Increasing task demands might reduce the ability of participants to make verbal or rational judgements that involve self-statements and consequently bring more basic learning mechanisms, such as associative learning, into play (Dickinson, 2001).

4.1.1 Design

To test this rationale, Experiment 4 was a replication of Experiment 3 but the demands of the task were increased by increasing the visual complexity of the VEs. Additional single shapes were presented throughout both training phases and the test phase (see Table 4.1, Figures 4.1 and 4.2) with the platform location remaining close to the perimeter of the target shapes. Figure 4.1 shows a first-person perspective view of the VE seen by half of the participants in phase 1.

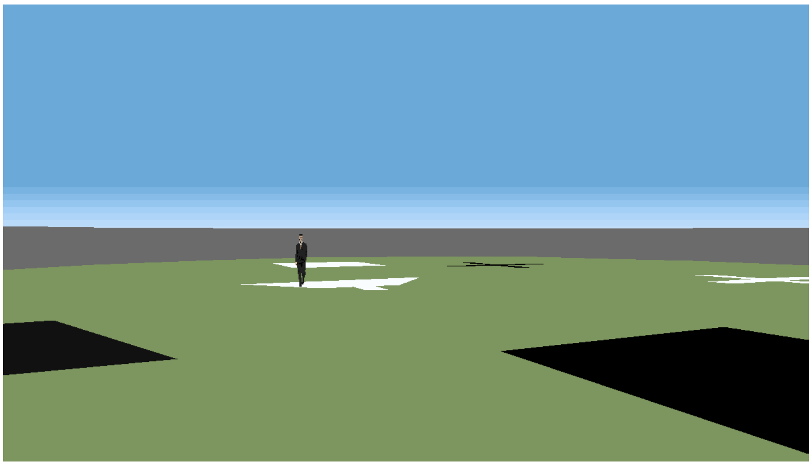

Figure 4.1. First-person perspective of the more complex VE used in phase 1 for half of the participants in Experiment 4. The human figure (never seen by participants) is located on the goal close to the perimeter of shape B, in this case the irregular white shape.

Group	Phase 1	Phase 2	Test
Experimental	A+,V, W, X, Y, Z	AB+, U,V, W, X, Y, Z	B+, V, W, X, Y, Z
Control	C+,V, W, X, Y, Z	AB+, U,V, W, X, Y, Z	B+, V, W, X, Y, Z

Table 4.1. The design of Experiment 4: U – Z were three black and three white shapes, presented singly in both training phases and the test.

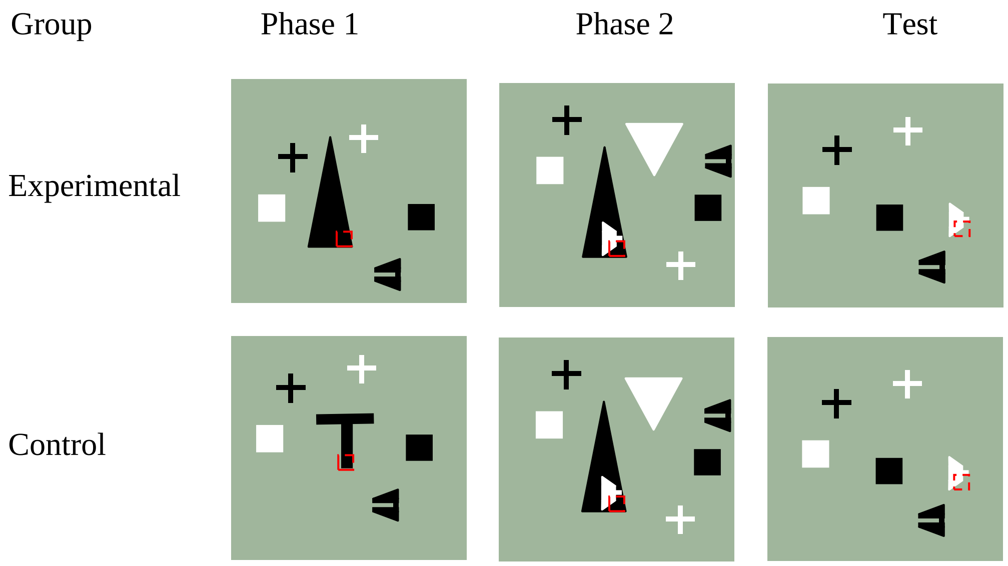

Figure 4.2. Scale plan layouts of the stimuli used in Experiment 4. Colour-control shapes were presented as individual cues in each phase. The only compounded cues were the black triangle and irregular white target shapes-AB in phase 2. See Appendix Figure A.7.3 for counterbalanced stimuli.

4.1.2 Method

4.1.2.1 Participants

There were 48 participants; two of whom were replaced as they showed no evidence of learning in at least one of the training phases. Those who participated had a mean age of 20.7 years (range: 18-57 years), and 20 were men; equal numbers of men served in experimental and control groups.

4.1.2.2 Apparatus

The VEs used were identical to those employed in Experiment 3 but with additional flat horizontal ‘colour-control’ cues on the ground throughout training and testing for both groups, as illustrated in Figure 4.2. In phase 1, in addition to shape-A (for group experimental) or shape-C (for group control), two white cues (a square and a cross) and three black cues (a square, a cross, and a second but differently shaped irregular-octagon) were presented (dimensions ranging between 4.1 and 4.6 m). These were roughly evenly spaced around the search area. In phase 2, in addition to the configuration of shapes-A and B (for all participants), the auxiliary cues from phase 1 were presented along with a white triangle (dimensions: base 9m, base to apex 9m). In phase 2, the colour-control cue shapes- U-Z were physically separated so that the only cues presented in a black-white configuration in phase 2 were the target shapes A and B.

4.1.2.3 Procedure

The procedure was identical to that in Experiment 2 (section 3.1.2.3) except the goal was close to the edge of the target cues. See Appendix Figure A.7.8 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

4.1.3 Results and discussion

Preliminary mixed 2 x 16 analysis of the phase 1 data, with shape (larger or smaller) as the between-participant factor, and trials as the repeated-measures factor, , found no main effect of stimulus, F (1, 46) = .310, MSE = 450, $p > .05$, $\eta_p^2 = .007$, and no interaction with this factor, F (2, 103) = .263, MSE = 2191, $p > .05$, $\eta_p^2 = .006$ [Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, F (1, 22) = .088, MSE = 517, $p > .05$, $\eta_p^2 = .014$, and no interaction with this factor, F (2, 40) = .728, MSE = 2545, $p > .05$, $\eta_p^2 = .013$ [Greenhouse-Geisser correction applied]. Trial by trial independent *t*-test analyses on both the above data sets, uncorrected for multiple comparisons, found no significant differences on any trial (*ts* < 2, *p*s > .05).

Therefore, as in Experiment 2 and 3, both larger and smaller shapes served equally well in guiding participants to the platform.

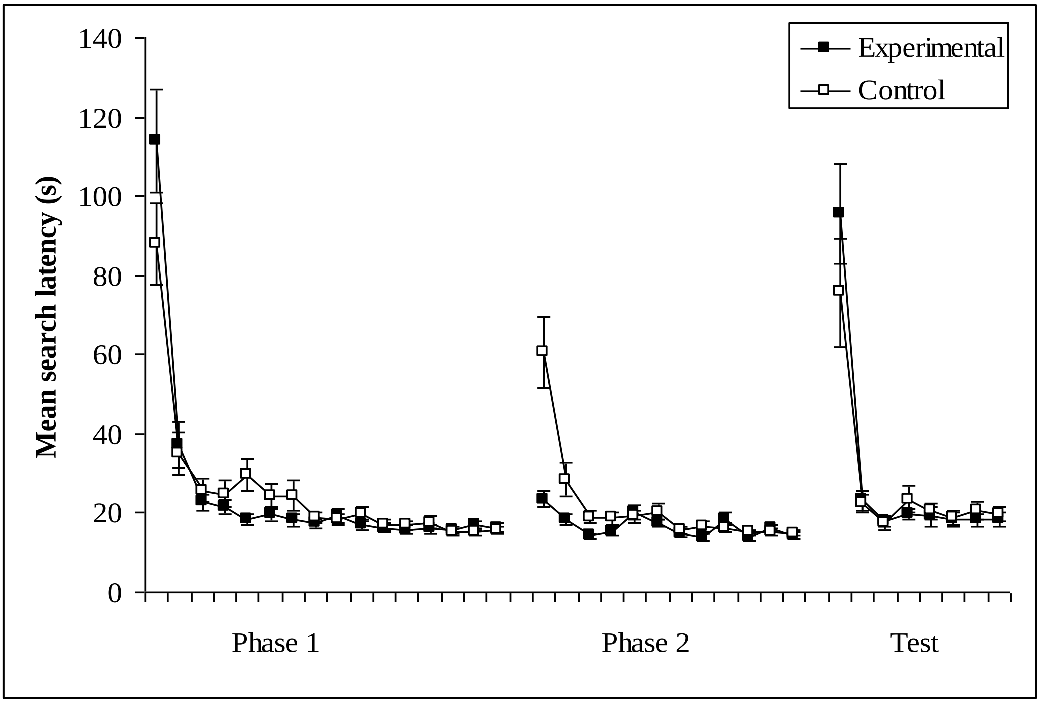

Figure 4.3 Experiment 4: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 1 are presented in the left panel of Figure 4.3. A 2 group (experimental and control) x 16 trials mixed ANOVA, found a main effect of trials, *F* (2, 106) = 67.13, *MSE* = 2032, *p* <.001, η_p^2 = .6 [Greenhouse-

Geisser correction applied]. Neither the main effect of group, *F* (1,46) = .031, *MSE* = 452, $p > .05$, $\eta_p^2 = .001$, nor the interaction between main effects, *F* (2,106) = 2.35, *MSE* = 2032, $p > .05$, $\eta_p^2 = .049$, [Greenhouse-Geisser correction applied],were statistically significant.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 4.3. A 2 group (experimental and control) x 12 trials mixed ANOVA on these data, found main effects of group, *F* (1, 46) = 14.9, *MSE* = 234, $p <.001$, $\eta_p^2 = .25$, and trials, *F* (2, 104) = 21.46, *MSE* = 633, $p < .001$, $\eta_p^2 = .32$ [Greenhouse-Geisser correction applied] and a Trial x Group interaction, *F* (2, 104) = 10.57, *MSE* = 633, $p < .001$, $\eta_p^2 = .19$. The main effect of trials reflects a reduction in mean latencies overall as training progressed. The group effect and the Trial x Group interaction reflect longer latencies in the control group. A trial by trial analysis found the control group to be slower on the first three trials, *ts* > 2.18, *ps* < .04, but there was no significant difference thereafter, *ts* < 2, *ps* > .05.

Mean latencies to find the platform in the test are presented in the right panel of Figure 4.3. Although the experimental group was numerically slower on the first test trial, this difference did not reach statistical significance, *t*(46) = 1.05, $p > .05$. A 2 group (experimental and control) x 8 trials mixed ANOVA on the test phase latencies, found a main effect of trials, *F* (1, 61) = 41.75, *MSE* = 3288, $p < .001$, $\eta_p^2 = .48$ [Greenhouse-Geisser correction applied], reflecting a reduction in search latencies as the test progressed. Neither the main effect of group, *F* (1, 46) = .379, *MSE* = 610, *p* >

.05, η_p^2 = .068, or Group x Trial interaction, F (1, 61) = 41.75, MSE = 3288, $p < .05$, η_p^2 = .023 [Greenhouse-Geisser correction applied] were significant.

The direction of test result, although failing to reach statistical significance was consistent with a blocking outcome, and opposite to the direction in Experiments 2 and 3. A 2 x 2 x 8 ANOVA on the test data, with experiment (3 and 4), group (experimental and control), and trials as factors found a main effect of experiment, $F(1,92) = 41.41$, MSE = 399, $p < .001$, η_p^2 = .31, reflecting longer overall search latencies in Experiment 4. However the Group x Experiment interaction failed to reach statistical significance, $F(1,92) = 2.87$, MSE = 399, $p > .05$, η_p^2 = .03.

Unlike the equivalent comparison in Experiment 3, the control group in Experiment 4 did not have statistically shorter search latencies than the experimental group on trial 1 of phase 1. Presumably (and consistent with casual observations) when presented with the additional colour-control shapes surrounding the T-shape in this phase, control participants in Experiment 4 did not follow a ‘path’ suggested by the T-shape but searched more randomly among the different shapes (cf. Experiment 8). In Experiment 3 it was suggested that presenting the T-shape alone promoted this search strategy and led to early platform discovery. It is difficult to envisage how this difference could have influenced the test results.

The aim of increasing the number of cues in Experiment 4 was to increase the complexity of the information to which the participants were exposed as suggested by Dickinson (2001; see De Houwer & Becker, 2002). Notwithstanding this increase in complexity, a comparison between latencies in Experiments 3 and 4 suggests that learning following initial trials in each experiment was very rapid. It might be anticipated that the presence of more shapes would result in deterioration in performance but there appears to be little difference in the ability of participants to learn, irrespective of the number of cues present. In Experiment 4, the initial trials in each phase latencies were longer than the equivalent trials in Experiment 3. Following initial exploration participants seemed to be able to efficiently return to the target shape and rapidly learn the specific goal location close to the perimeter on subsequent trials.

Examination of the raw data suggested that longer search latencies in the control participants in Experiment 4 was at least in part due to poor learning about the triangle when it served as shape-B for half of the control participants. Apparently these control participants in Experiment 4 who were trained with the small T-shape as shape-C in phase 1 (and hence experienced all smaller shapes in phase 1) paid attention to the smaller odd-octagon rather than the larger triangle when these shapes were compounded as shape-AB in phase 2. This influence of physical size on learning was not apparent in Experiments 2, or 3. When this generalization influence is taken into account, increasing complexity could make cue competition the more probable outcome. The apparent ease of learning in Experiment 4 indicates that the level of VE complexity did not increase task demands sufficiently to produce a clear blocking effect. In addition, as the auxiliary cues introduced in phase 2 were presented individually rather than in compound, the target shapes A and B were the only shapes that appeared in compound. This may have had the effect of drawing attention to the component shapes that formed the target compound. These issues were addressed in Experiment 5 by first: presenting compounded groups of colour-control shapes along with the target compound in phase 2. Second, participants were also required to perform a concurrent counting task to reduce their ability to make rational judgements and to increase the complexity of the task.

4.2 Experiment 5

The rapid learning seen in Experiment 4 suggested that the task demands might have been insufficiently complex to interfere with learning via rational mechanisms and bring associative learning into play. To address this issue, the cognitive demands of the task were increased in Experiment 5 by introducing a distracter task (cf. Aitken, Larkin & Dickinson, 2001) in which participants were requested to continuously count aloud during exploration. Furthermore in phase 2, the six auxiliary shapes were presented as three black and white compounds to increase the difficulty in identifying the correct compound.

Pilot work with a few participants suggested that spatial learning was disrupted to a surprising extent when participants were asked to count backwards in 3s from a predefined number. Typically this resulted in a very erratic pattern of latencies and the consequent failure to reach asymptotic learning by the end of the sixteen trials of phase 1 training. Therefore, it was decided to investigate high and low difficulty distracter conditions. Participants in the low difficulty condition were asked to count forwards in multiples of one starting from the number one; participants in the high difficulty condition were requested to count backwards in multiples of two starting from 599. To the extent that increasing task difficulty reduces verbal processing and engages less rationally-based learning mechanisms, cue-competition effects were anticipated to be more evident under these conditions of increased difficulty.

4.2.1 Design

Group	Phase 1	Phase 2	Test
Experimental	A+,V, W, X, Y, Z	AB+, UV WX, YZ	B+, V, W, X, Y, Z
Control	C+,V, W, X, Y, Z	AB+, UV WX, YZ	B+, V, W, X, Y, Z

Table 4.2. The design of Experiment 5: U – Z were three black and three white shapes. In phase 1 shapes V – Z were presented singly. In phase 2, both groups were presented with a compound of shapes A and B together with three other black and white distracter compounds made from shapes U – Z.

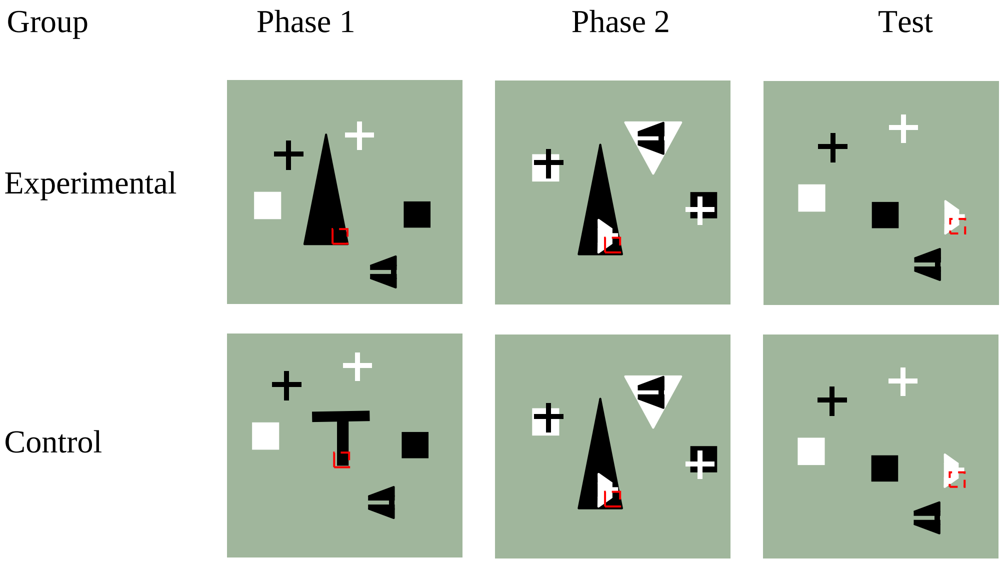

Figure 4.4. Scale plan layouts of the stimuli used in Experiment 5. Distracter cues were added to each training phase and the test. See Appendix Figure A.7.4 for counterbalanced stimuli.

4.2.2 Method

4.2.2.1 Participants

There were 48 participants with a mean age of 22.5 years (range: 18-50 years), and 22 were men. They were randomly allocated to two groups with the constraint that equal numbers of men served in both groups.

4.2.2.2 Apparatus

The apparatus was identical to that in Experiment 4 except that the colour-control shapes formed three additional black-white configurations (UV, WX, YZ) in phase 2. The compounding of the colour-control cues ensured that locating the platform in phase 2 could not be based on approaching a black and white configuration. In phase 2, the locations of the shape-AB configuration and the additional configurations were randomly changed after each block of 4-trials. In the test, for all participants shape-B was presented without shape-A, along with the colour-control shapes from phase 1 (see Table 4.2 and Figure 4.4)

4.2.2.3 Procedure

The procedure was identical to that of Experiment 2 (section 3.1.2.3), except that participants were requested to count aloud throughout each trial from the moment they started to explore the environment until they located the platform. Twelve participants in each group were asked to count forwards in multiples of one starting from one; the remaining participants were requested to count backwards in multiples of two starting from 599.

See Appendix Figure A.7.9 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

4.2.3 Results and discussion

Preliminary analyses on the levels of distracter difficulty established that, in comparison with forward counting, counting backwards in twos significantly retarded search latencies in the test only, but there were no interactions between counting task and other factors of interest in any phase; therefore, levels of distraction was not included as a factor in the following analyses.

As in previous experiments, the influence of size of the shapes was assessed in phase 1. A preliminary mixed 2 x 16 ANOVA analysis of the phase 1 data, with shape (larger or smaller) as the between-participant factor, and trials as the repeated-measures factor, found no main effect of stimulus, F (1, 46) = 3.408, MSE = 648, $p > .05$, $\eta_p^2 = .069$, and no interaction with this factor, F (2, 104) = .357, MSE = 2476, $p > .05$, $\eta_p^2 = .008$ [Greenhouse-Geisser correction applied]. Similar ANOVA analysis specifically on the triangle and irregular-octagon data from the experimental group in phase 1, found a main effect of stimulus, F (1, 22) = 7.70, MSE = 475, $p = .01$, $\eta_p^2 = .26$, but the interaction between main effects was not significant, F (2, 44) = 1.915, MSE = 2759, $p > .05$, $\eta_p^2 = .008$ [Greenhouse-Geisser correction applied]. In this experiment, participants were faster to find the platform when the larger shape (the triangle) served as shape-A, which strengthens the case presented above that participants must have been using the geometric properties of the shape as location indicators and were not randomly searching for the platform.

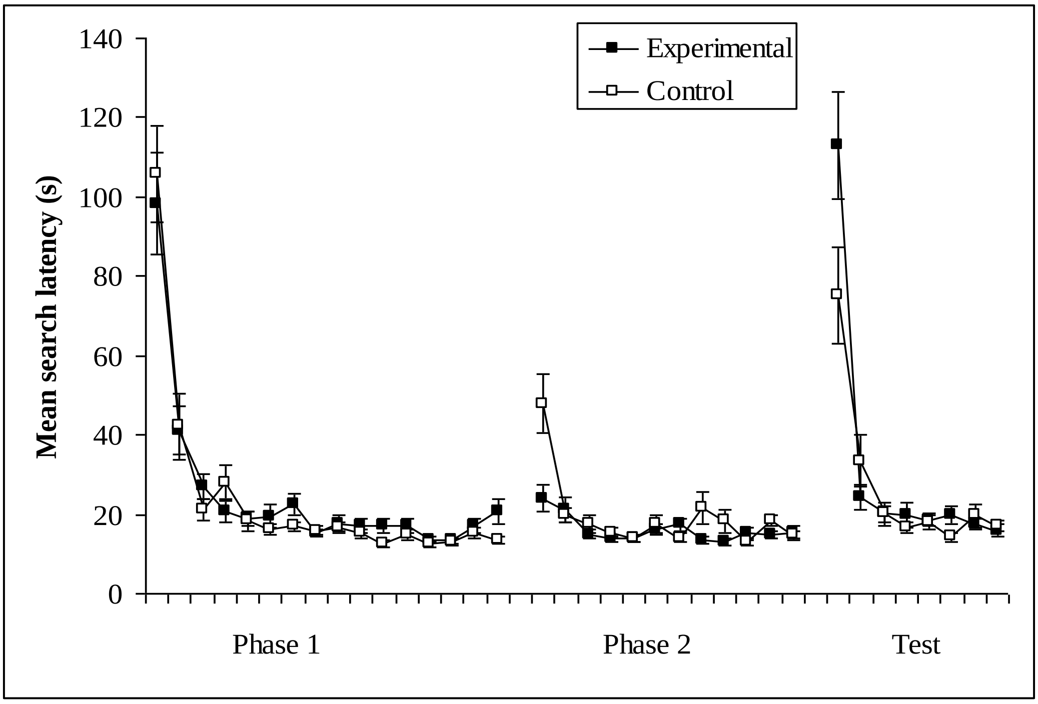

Figure 4.5. Experiment 5: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 1 are presented in the left panel of Figure 4.5. A 2 group (experimental and control) x 16 trials mixed ANOVA found a main effects of trials, *F* (2, 104) = 61.51, *MSE* = 2470, $p < .001$, $\eta_p^2 = .57$ [Greenhouse-Geisser correction applied], but neither the main effect of group, *F* (1, 46) = .403, *MSE* = 690, $p > .05$, $\eta_p^2 = .009$, nor the interaction between main effects , *F* (2, 104) = .552, *MSE* = 2470, $p > .05$, $\eta_p^2 = .012$ [Greenhouse-Geisser correction applied] was significant.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 4.5. A 2 group x 12 trials mixed ANOVA found main effects of trials, *F* (3, 141) = 13.96, *MSE* = 439, *p* < .001, η_p^2 = .23, and group, *F* (1, 46) = 6.47, *MSE* = 233, *p* =.014, η_p^2 = .12, and a Trial x Group interaction, *F* (3, 141) = 5.20, *MSE* = 439, *p* = .002, η_p^2 = .10. The group effect and the Trial x Group interaction reflect longer latencies in the control group on trial 1, *t*(32) = 3.003, *p* < .01, but no significant difference by trial 12, *t*(46) = .332, *p* > .05.

Mean latencies to find the platform in the test are presented in the right panel of Figure 4.5. A statistically significant difference between groups was apparent on the first test trial, *t*(46) = 2.10, *SE* = 18.1, *p* = .04, $\eta^{2\,=}$ .09. A 2 group x 8 trials mixed ANOVA on the latencies for the whole test phase, found main effects of trials, *F* (2, 72) = 53.77, *MSE* = 2816, *p* < .001, η_p^2 = .54, and a Trial x Group interaction, *F* (2, 72) = 3.86, *MSE* = 2816, *p* = .04, η_p^2 = .08 [Greenhouse-Geisser correction applied]. The Trial x Group interaction reflects significantly slower responding in the experimental group on trial 1, *t*(46) = 2.095, *p* < .05, but no significant difference by trial 8, *t*(46) = .301, *p* > .05.

Experiment 5 found evidence of blocking of location learning based on large room-sized shapes. Despite the identical exposure to shape-B during phase 2 and the test phase for both groups, prior experience with shape-A as a location indicator in the experimental group reduced their ability to use shape-B as a location indicator in the test. This demonstration of cue competition suggests that processing large shapes is, at least under some circumstances, subject to the same effects as causal and contingency learning, and is contrary to predictions derived from the proposal of a specialised geometric module. It appears that procedural factors govern whether cue competition is evident in spatial learning; what remains to be specified is which factors are responsible, and how they operate.

The blocking effect on trial 1 of the test phase in Experiment 5 is consistent with the experimental hypothesis that increasing task difficulty engages different, possibly associative, learning mechanisms which are more sensitive to cue competition. However, aspects to the data from Experiment 5 question an associative interpretation. Increasing task difficulty in Experiment 5 might be anticipated to lead to less steep learning curves than in Experiment 3. Comparison of Figures 3.6 and 4.5 suggests that although search latencies were slightly longer and more variable in Experiment 5, both experiments produced very similar overall search patterns except at two points. The only interesting difference in performance between Experiments 3 (a clear non-blocking effect was found) and 5 (a clear blocking effect found) is the critical finding that search latencies on the first test trial of Experiment 5 were much longer than on the equivalent trial of Experiment 3 in both groups. For the experimental group, this effect was so great that the cue-interaction outcome was reversed from a clear failure to find blocking in Experiment 3 to a clear demonstration of blocking in Experiment 5.

4.3 Experiment 6

4.3.1 Design

The counting task in Experiment 5 and in particular its more difficult variant was anticipated to reduce rational rule-based processing. In terms of the demands of the spatial task, it was anticipated that the type of rational processing that participants might engage in could be equivalent to covert self-statements such as: "the target is at the bottom-right vertex of the triangle". However, an approximation to one-trial learning was seen in both training and the test phases of Experiment 5. One-trial learning suggests the operation of a propositional or rational reasoning mechanism, rather than a gradual learning process based on trial and error. However, it could be that, whether distracted or not, adults are so used to finding goals in geometric surroundings that shape is detected and used automatically. Experiment 6 investigated whether the crucial manipulation that promoted blocking was interference with self statements as a consequence of the distracter task. In an otherwise exact replication of Experiment 5, participants were not required to perform a distracter task while learning. Evidence of blocking of learning in Experiment 6 would indicate that the introduction of the additional auxiliary shapes was the pivotal factor that changed the non-blocking finding in Experiment 3 to the blocking finding in Experiment 5, rather than the distracter task.

4.3.2 Method

4.3.2.1 Participants

There were 48 participants; five of whom were replaced as they showed no evidence of learning in at least one of the training phases. Those who participated had a mean age of 21.7 years (range: 18-33 years), and 24 were men; equal numbers of men served in experimental and control groups.

4.3.2.2 Apparatus

The VEs used in Experiment 6 were identical to those employed in Experiment 5 in all phases. However, an adjustment problem meant that movement through the VE was consistently faster (≈ 28%) throughout Experiment 6 than throughout Experiment 5.

4.3.2.3 Procedure

The procedure was identical to that in Experiment 2 (section 3.1.2.3). See Appendix Figure A.7.9 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

4.3.3 Results and discussion

Preliminary mixed 2 x 16 analysis of the phase 1 data, with shape (larger or smaller) as the between-participant factor, and trials as the repeated-measures factor, , found no main effect of stimulus, F (1, 46) = .967, MSE = 661, $p > .05$, $\eta_p^2 = .021$, and no interaction with this factor, F (2, 87) = .283, MSE = 2223, $p > .05$, $\eta_p^2 = .006$

[Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, *F* (1, 22) = .044, *MSE* = 942, *p* > .05, η_p^2 = .002, and no interaction with this factor, *F* (2, 39) = .099, *MSE* = 3451, *p* > .05, η_p^2 = .004 [Greenhouse-Geisser correction applied].

Mean latencies to find the platform in phase 1 are presented in the left panel of Figure 4.6. A 2 group x 16 trials mixed ANOVA, found a main effect of trials, *F* (2, 87) = 38.56, *MSE* = 2200, *p* <.001, η_p^2 = .46 [Greenhouse-Geisser correction applied]. Neither the main effect of group, nor the interaction between main effects, was statistically significant (*p*s > .05).

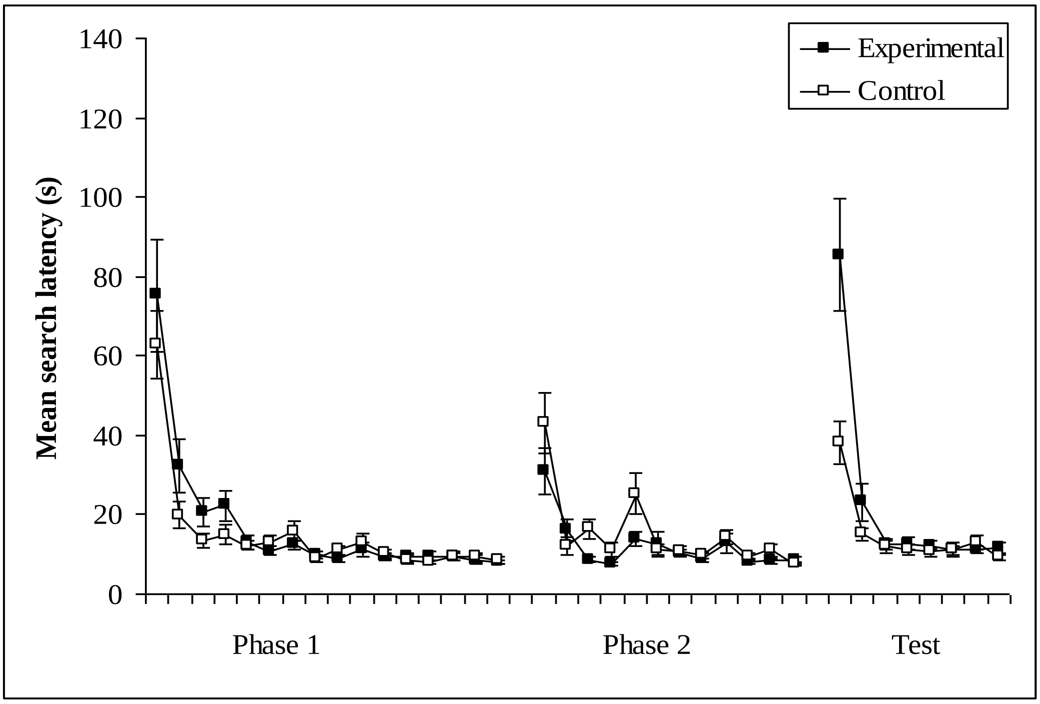

Figure 4.6. Experiment 6: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 4.6. A 2 group x 12 trials mixed ANOVA on these data, found main effects of group, F (1, 46) = 4.91, MSE = 253, p = .03, η_p^2 = .10, and trials, F (3, 116) = 18.25, MSE = 721, p < .001, η_p^2 = .28 [Greenhouse-Geisser correction applied]. The interaction between main effects was not statistically significant, F (3, 116) = 1.836, MSE = 721, p > .05, η_p^2 = .038 [Greenhouse-Geisser correction applied]. Although the interaction was not significant, a trial by trial analysis found that the main effect of group reflects longer latencies in group control than group experimental on trials 3, 4 and 5 only (*ts* > 2 *ps* < .05); the main effect of trials reflects a reduction in mean latencies overall as training progressed.

Mean latencies to find the platform in the test are presented in the right panel of Figure 4.6. A statistically significant difference between groups was apparent on the first test trial, $t(46)$ = 3.13, SE = 15.1, p = .003, η_p^2 = .18. A 2 group x 8 trials mixed ANOVA on the test phase latencies, found main effects of group, F (1, 46) = 9.04, MSE = 587, p = .004, η_p^2 = .16, and trials, F (1, 61) = 38.57, MSE = 2038, p < .001, η_p^2 = .46, and a Trial x Group interaction, F (1, 61) = 8.31, MSE = 2038, p = .003, η_p^2 = .15 [Greenhouse-Geisser correction applied]. The Trial x Group interaction reflects much slower responding in the experimental group on trial 1, $t(30)$ = 3.133, p < .01, but no significant difference thereafter, (*ts* < 2, *ps* > .05)

Evidence for blocking of learning about one ‘room-sized’ shape by another room-sized shape as a location indicator was evident in Experiment 5 even though participants were not required to complete a concurrent distracter task. Despite lower overall latencies than in Experiment 6, which probably reflects a difference in speed of movement within the respective VEs, the pattern of data between experiments was very similar. Thus, it appears that the crucial change from Experiment 3 to Experiments 5 and 6 that was responsible for the emergence of cue competition must lie in the presentation of larger numbers of cues throughout training, rather than on the demands of the counting distracter task.

A further point of interest relates to the longer latencies by the control group in Experiment 6 when the arrangement of cues was changed on trial 5 of phase 2 training. Although smaller, this difference replicated the effect found in Experiment 2 when participants piloted to find the platform that was distal to the target shape. In Experiment 2 the presence of a colour-control cue also potentially provided consistent location information for the first four trials of phase 2. The implication was that during the initial block of trials of phase 2, Experiment 2 participants were able to use both compound cues to help locate the platform. However, the relationship between the colour-control cue and the platform did not remain constant and participants subsequently learned to rely solely on the target compound to find the platform. The discrepancy on trial 5 of Experiment 6 can be explained in similar terms, as the three colour-control compounds presented in phase 2, whilst not immediately adjacent to the platform location, were available to provide consistent localization information on the initial four trials (see Appendix Figure A 7.9). On trial 5 the arrangement of colour-control shapes changed but the platform stayed in the same location relative to the target shapes. If participants had used the colour-control shapes to aid platform localization on the initial trials of phase 2, subsequent attempts to use them would disrupt learning because only the target shapes consistently predicted the platform location throughout phase 2. As in Experiment 2, by the end of phase 2, both groups performed equally well. Given that both groups reached asymptotic learning by the end of phase 2 it is hard to see how the disruption in learning for the control group on trial 5 impacts on the test result. What it does perhaps indicate is how participants modify their behaviour according to how accurate cues are at predicting a location.

CHAPTER 5

ABSENCE OF BLOCKING WITH COMPLEX TEST CONDITIONS AND SIMPLIFIED TRAINING

5.1 Experiment 7

Experiment 6 replicated the blocking effect found in Experiment 5 and confirmed that cue competition between large scale shapes is experimentally reliable. Furthermore, blocking in Experiment 6 was found when participants were not required to perform the concurrent distracter task that was intended to suppress rational learning in Experiment 5. This comparison means that the emergence of cue competition cannot be attributed to the concurrent distracter task. Given that the blocking design was essentially identical between Experiments 3-6, and the distracter manipulation was not crucial in producing blocking, the critical variable must be the number and arrangement of auxiliary shapes.

While in Experiment 4 an outcome in the direction of blocking was found, this did not reach statistical significance, probably because in phase 2 training, auxiliary shapes were presented individually. As the target shapes, A and B, formed the only black and white compound in phase 2, attention in the experimental group may have been drawn to the components of this compound with the result that blocking was attenuated. Thus, while the direction of outcome of Experiment 4 is consistent with blocking, interpretation is clouded by how cues were presented in phase 2 training. Therefore, the appropriate comparison of the conditions that lead to a change from no blocking to blocking lies in a comparison between Experiment 3 (no blocking) and Experiments 5 and 6 (clear blocking).

The differences in shape presentations between Experiments 3, 5 and 6 were: In phase 1 of Experiment 3, shape-A was trained alone, but in phase 1 of Experiments 5 and 6 shape-A was trained in the context of 5 auxiliary shapes. In phase 2 of Experiment 3, one configuration of auxiliary shapes was presented in addition to the shape-AB configuration, but 3 configurations of auxiliary shapes were presented in phase 2 of Experiments 5 and 6. In the test phase, a single auxiliary shape was present in Experiment 3, but 5 auxiliary shapes were present in Experiments 5 and 6. Differences in cue competition outcomes might be due to the auxiliary stimuli present during phases 1 and 2 when learning and encoding of shape localization information took place. Alternatively, cue competition could depend on differences in retrieval of this information during the test phase.

Theories of cue competition (Mackintosh, 1975; Rescorla & Wagner, 1972) do not offer an account of why or how auxiliary shapes, might influence cue competition. These accounts predict that irrelevant stimuli should rapidly lose processing resources and become ‘neutral’ with respect to the target. The auxiliary shapes in the current experiments were essentially irrelevant as they did not provide consistent localization information in comparison to the target shapes. However, an account of the different outcomes between Experiment 3 and Experiments 5 and 6 can be developed based on the number of cues in the test environments. The platform was located on one of only two shapes presented in the test in Experiment 3 and perhaps this made the target too easy to find for both experimental and control groups. Thus any group differences might have been masked by a ceiling effect in Experiment 3; but the increase in auxiliary cues in Experiments 5 and 6, might have removed this masking effect and allowed a group difference to become apparent in Experiments 5 and 6.

Although possible, masking seems unlikely given the direction of facilitation suggested by the results of Experiment 3. If masking had occurred we would expect no difference in direction between groups. To address the influence of the number of test shapes in the test, Experiment 7 examined whether masking, or another unspecified influence of the number of cues, was present. The same training procedures and VE arrangement used in Experiment 3 were adopted in phases 1 and 2, but the numbers of test shapes were increased by using the same test arrangements as in Experiments 5 and 6. The hypothesis was that if the number of cues in the test was responsible for the emergence of blocking, then training as carried out in Experiment 3 should lead to evidence of blocking when more auxiliary shapes are presented in the test. No blocking in Experiment 7 would implicate the increased cues in the learning phases rather than the test phase in determining cue competition.

5.1.1 Design

Group	Phase 1	Phase 2	Test
Experimental	A+	AB+, YZ	B+, V, W, X, Y, Z
Control	C+	AB+, YZ	B+, V, W, X, Y, Z

Table 5.1. The design of Experiment 7: phases 1 and 2 were identical to Experiment 3. The test phase was identical to that in Experiments 4, 5 and 6.

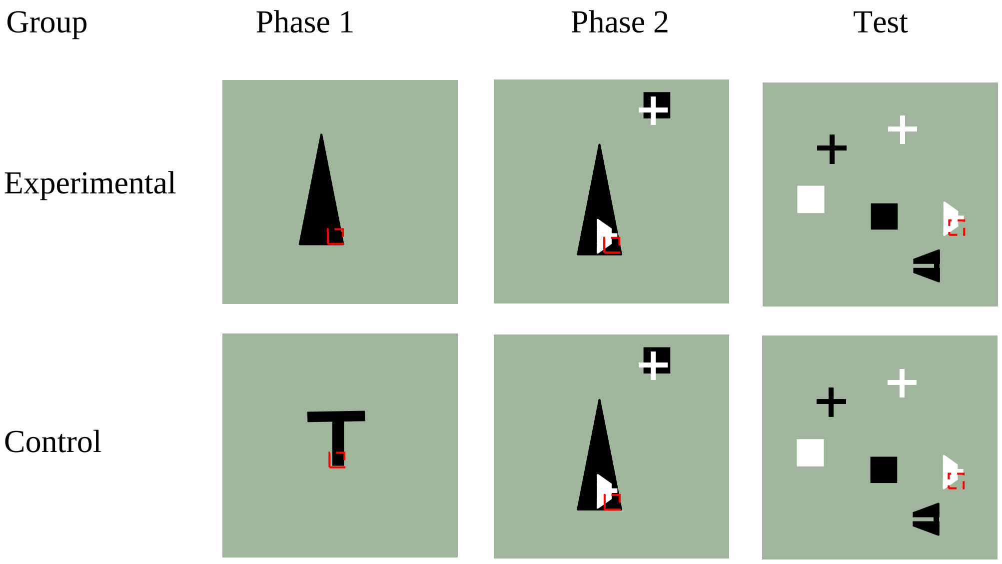

Figure 5.1. Scale plan layouts of the stimuli used in Experiment 7. See Appendix Figure A.7.5 for counterbalanced stimuli.

5.1.2 Method

5.1.2.1 Participants

There were 48 participants who had a mean age of 19.7 years (range: 18-33 years), and equal numbers of men and women served in experimental and control groups.

5.1.2.2 Apparatus

The VEs used in phases 1 and 2 were identical to those employed in Experiment 3 (see section 3.1) where a single shape was presented in phase 1 and in phase 2 a colour-control compound - YZ accompanied the target shape compound -AB. The test phase was identical to those used in Experiments 4, 5 and 6 (see section 4.1).

5.1.2.3 Procedure

The procedure was identical to that in Experiment 2 (section 3.1.2.3). See Appendix Figure A.7.7 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

5.1.3 Results and discussion

Preliminary mixed 2 x 16 analysis of the phase 1 data, with shape (larger or smaller) as the between-participant factor, and trials as the repeated-measures factor, , found no main effect of stimulus, F (1, 46) = .081, MSE = 445, p > .05, η_p^2 = .002, and no interaction with this factor, F (2, 73) = 1.065, MSE = 3578, p > .05, η_p^2 = .023 [Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, F (1, 22) = .986, MSE = 265, p > .05, η_p^2 = .043, and no interaction with this factor, F (2, 33) = 1.414, MSE = 3927, p > .05, η_p^2 = .06 [Greenhouse-Geisser correction applied].

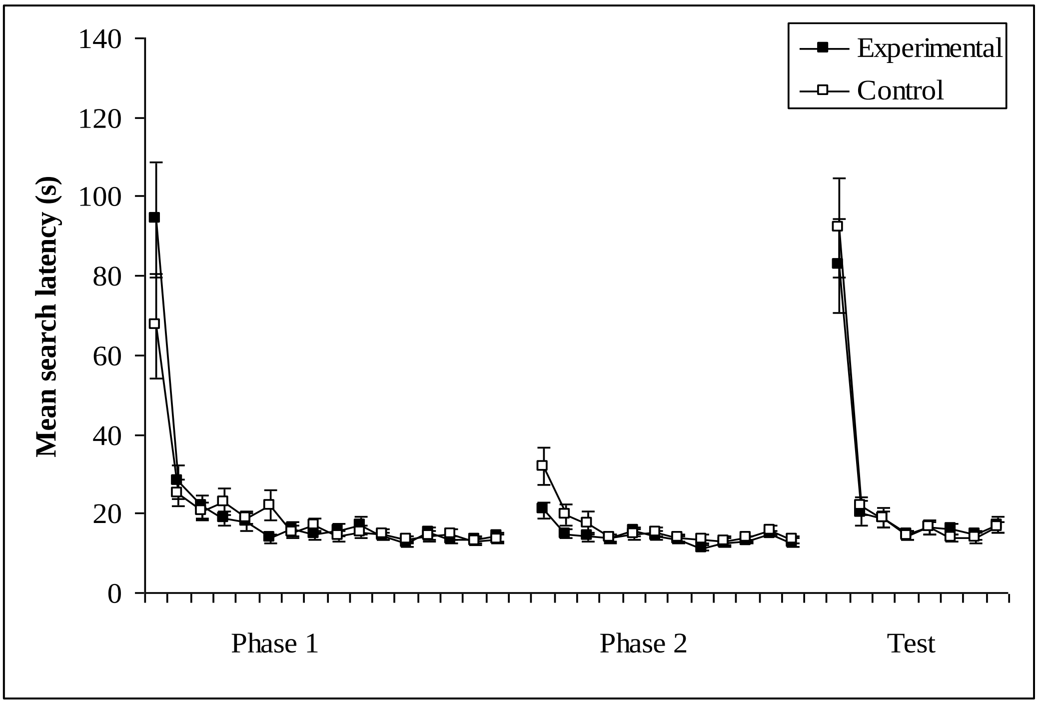

Figure 5.2. Experiment 7: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

The data from phase 1 are presented in the left hand panel of Figure 5.2. A mixed 2 group x 16 trials ANOVA on these data found a significant main effect of trials, *F* (2, 73) = 34.81, *MSE* = 3510, $p < .001$, $\eta_p^2 = .43$, but no main effect of group, *F* (1, 46) = .604 , *MSE* = 266, $p > .05$, $\eta_p^2 = .013$, and no interaction between trials and group, *F* (2, 73) = 1.732, *MSE* = 3510, $p > .05$, $\eta_p^2 = .036$. The data from phase 2 are presented in the middle panel of Figure 5.2. A similar mixed ANOVA on these data found main effects of group, *F* (1, 46) = 10.88, *MSE* = 57.5, $p < .01$, $\eta_p^2 = .19$, and trials, *F* (4, 174) = 10.61, *MSE* = 187, $p < .001$, $\eta_p^2 = .19$, but no interaction, *F* (4, 174)

= 1.852, *MSE* = 187, $p > .05$, $\eta_p^2 = .039$. The group main effect reflects slightly faster search by group experimental, predominantly on the first three trials of this phase.

Mean latencies to find the platform in the test are presented in the right panel of Figure 5.2. No differences were apparent between the groups in their ability to locate the platform. An independent *t*-test on the first test trial found that groups did not differ statistically, $t(46) < 1$, $p > .05$. A 2 group x 8 trials mixed ANOVA on all the test data, found a main effects of trials, $F\ (1, 58) = 59.23$, *MSE* = 2819, $p < .001$, $\eta_p^2 = .56$, but neither the main effect of group, nor the interaction between trials and group, were significant ($p > .05$).

In Experiment 7, participants had identical training to that in phases 1 and 2 of Experiment 3, but in the test, shape-B was presented among five auxiliary shapes rather than a single shape. The non-significant direction of effect was opposite to blocking, consistent with that found in Experiment 3. The failure to find blocking in Experiment 7 is not due to ease with which shape-B can be located in the test procedure as blocking was found using identical test parameters and stimuli in Experiments 5 and 6. The main finding from Experiment 7, therefore, is a second sound demonstration that blocking did not occur. As in Experiment 3, one large-scale shape failed to compete with a second large-scale shape, providing further evidence consistent with the suggestion of Cheng (1986) and Gallistel (1990) that processing geometric cues should not lead to cue competition. Nevertheless, clear blocking was found in Experiments 5 and 6 when more auxiliary shapes were presented in all stages of the procedure. Experiment 7 indicated that the test parameters were not crucial to whether blocking is found. The conclusion therefore is that the conditions in the learning phases are fundamental to promoting the blocking effect.

CHAPTER 6

NO BLOCKING WITH SINGLE CUE IN INITIAL TRAINING AND MULTIPLE CUES IN SUBSEQUENT PHASES

6.1 Experiment 8

The comparison between Experiments 5 and 6 and Experiment 7 confirms that a factor other than the test procedure determines whether or not blocking of spatial learning between shapes will be found. Therefore, the source of the blocking effect is at the stage of encoding of spatial information rather than at retrieval. The outcomes of Experiments 3-7 suggests that introducing more auxiliary cues into either, phase 1 or phase 2, or into both phases, is the factor that promotes blocking. Given the blocking design, phase 1 learning is the most likely source of cue-competition effects because in phase 2 both experimental and control participants are exposed to the same sets of shapes. In phase 1 of Experiments 3 and 7, a shape (A or C, for groups experimental and control respectively) was presented in isolation, and blocking did not occur. In phase 1 of Experiments 5 and 6, auxiliary cues were also present, and blocking was found. This suggests that blocking between shapes depends on the need for participants to make an initial discrimination between the target and auxiliary shapes. This initial stage of learning was only required in Experiments 5 and 6 when shape-A was presented with five other shapes.

In established accounts of cue competition it is not predicted that discrimination learning during initial training is required for blocking to occur. An explanation of the current set of results can however be offered by appeal to an account developed in the spirit of Mackintosh's (1975) attentional theory of learning. Mackintosh (1975) proposed that if stimuli are relevant to the solution of a problem then attention to them will increase, but if irrelevant, attention to them will decrease. In terms of this account, in the current experiments, attention should increase to shapes-A (for the experimental group) and -C (for the control group) in phase 1 as they are relevant for finding the goal. In phase 2, when all participants explore shape-AB, attention to shape-A will be greater in the experimental group because they have learned that this shape is a good predictor of the goal location in phase 1. For this group, attention to shape-A will increase or be maintained in phase 2, but attention to shape-B will decline because it does not enhance the ability of participants to locate the target given the presence of shape-A. The control group learn about shape-C and the target location in phase 1, but this experience is irrelevant in phase 2 because experience of shape-C is limited to phase 1. Instead, for the control group, both shapes-A and -B are equally relevant for finding the platform. Thus, attention to both shapes-A and -B will be maintained and more will be learned about shape-B than in the experimental group.

Mackintosh's theory can therefore be interpreted as predicting blocking in all the present series. However, according to this theory, attention will decline to any shapes that are irrelevant for finding the platform in phase 1. Therefore, attention will rapidly decline to the auxiliary shapes presented in phase 1 of Experiments 5 and 6. The effect of a decline in attention to irrelevant shapes is that learning in Experiments 5 and 6 should effectively be the same as in Experiments 3 and 7 in which no auxiliary shapes were presented in phase 1. Therefore, Mackintosh's theory predicts blocking in all four experiments.

Adopting the assumption that a tendency or strategy to ignore stimuli can generalize between phases, it might be possible to account for the present pattern of effects. If shape-A is initially trained in the presence of auxiliary shapes (Experiments 5 and 6), an initial process of learning which shape to attend to by default will also involve learning which shapes to ignore. Following this initial discrimination process, the geometric properties of shape-A will be used to locate the target. If we assume that a tendency to attend to shape-A and ignore all other shapes develops in phase 1, then in phase 2, the experimental group might continue to ignore all shapes or shape configurations other than shape-A. Therefore, they will not attend to shape-B. This tendency to ignore all other stimuli will not be so strong in the experimental groups that do not experience auxiliary shapes in phase 1 (i.e., in Experiments 3 and 7). If these experimental groups did not adopt the strategy of ignoring all cues other than shape-A, they should have processed shape-B to a greater extent.

For the control groups, whether or not they learn something equivalent to 'attend to shape-C and ignore everything else' in phase 1 is irrelevant to their task in phase 2 as shape-C is not encountered again after phase 1. In order to find the target in phase 2 they must attend to all the cues present, and learn that the shapes forming the shape-AB configuration are most relevant for finding the target. Therefore, regardless of whether auxiliary shapes are present or not, the control group should attend normally to shape-B and to no less or greater extent than shape-A.

The prediction from the above account is that if groups are trained with the sets of shapes used in Experiments 5 and 6 (which resulted in blocking) but without the auxiliary cues that were included in phase 1, blocking should not be found. This is because in phase 1 group experimental will not develop a strategy which generalises to phase 2 i.e. to ignore all cues other than shape-A (see Table 6.1)

6.1.1 Design

Group	Phase 1	Phase 2	Test
Experimental	A+	AB+, UV WX, YZ	B+, V, W, X, Y, Z
Control	C+	AB+, UV WX, YZ	B+, V, W, X, Y, Z

Table 6.1. The design of Experiment 8: phase 1 was identical to that used in Experiments 2 and 7; phases 2 and the test were identical to Experiments 4 and 5.

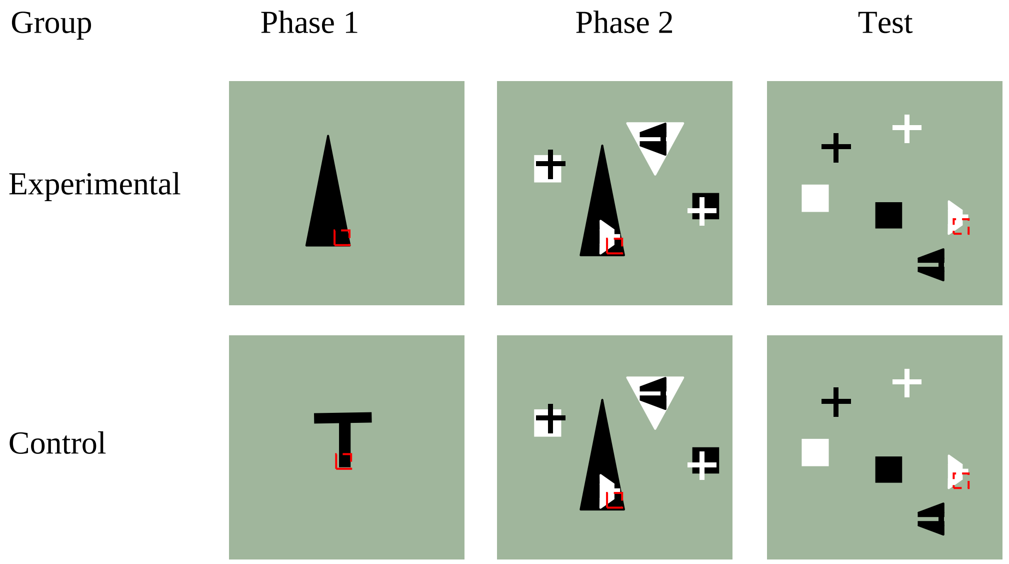

Figure 6.1. Scale plan layouts of the stimuli used in Experiment 8. See Appendix Figure A.7.6 for counterbalanced stimuli.

6.1.2 Method

6.1.2.1 Participants

There were 48 participants; two participants were replaced as they showed little or no evidence of learning in at least one of the training phases. Those who participated had a mean age of 19.2 years (range: 18-27 years), and 21 were men; 10 of which were in the experimental group.

6.1.2.2 Apparatus

The VEs used in phase 1 were identical to those employed in Experiment 3 (see section 3.1.1) where a single shape was presented to participants. In phase 2 and the Test phase the VEs were identical to those used in Experiments 5 and 6 (see section 4.2.1). For phase 2, three black and white colour-control compounds were presented along with the target compound of shapes A and B. In the test five individual shapes were presented along with the test shape-B.

6.1.2.3 Procedure

The procedure was identical to that in Experiment 2 (section 3.1.2.3). See Appendix Figure A.7.9 for the arrangements of the target compound (AB) and the colour-control compound locations on each block of four trials.

6.1.3 Results and discussion

Preliminary mixed 2 x 16 analysis of the phase 1 data, with shape (larger or smaller) as the between-participant factor, and trials as the repeated-measures factor, found no main effect of stimulus, F (1, 46) = .005, MSE = 510, p > .05, η_p^2 = .000, and no interaction with this factor, F (2, 114) = .690, MSE = 1767, p > .05, η_p^2 = .015 [Greenhouse-Geisser correction applied]. A similar ANOVA analysis specifically on the data from the triangular and irregular-octagon shapes presented for the experimental group also found no main effect of stimulus, F (1, 22) = .023, MSE = 509, p > .05, η_p^2 = .001, and no interaction with this factor, F (2, 52) = 1.27, MSE = 2656, p > .05, η_p^2 = .055 [Greenhouse-Geisser correction applied].

Mean latencies to find the platform in phase 1 are presented in the left panel of Figure 6.2. A 2 group x 16 trials mixed ANOVA found main effects of group, *F* (1, 46) = 25.00, *MSE* = 330, *p* < 001, η_p^2 = .35, and trials, *F* (3, 118) = 28.83, *MSE* = 1480, *p* < .001, η_p^2 = .39, and a Trial x Group interaction, *F* (3, 118) = 7.71, *MSE* = 1480, *p* < .001, η_p^2 = .14, [Greenhouse-Geisser correction applied]. Both the group effect and the interaction reflect faster responding by the control group on trials 1, 2, and 6 only, *ts* > 2.265, *ps* < .05.

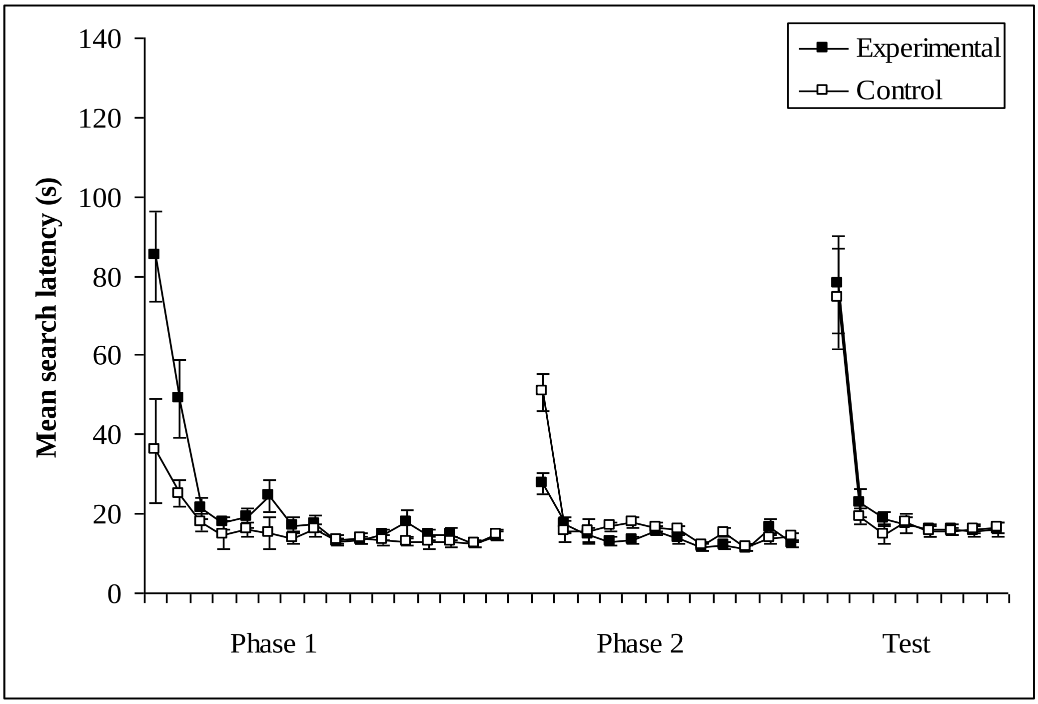

Figure 6.2. Experiment 8: mean search latencies for experimental and control groups for the 16 trials in phase 1, 12 trials in Phase 2, and 8 test trials. Error bars represent one estimated standard error above and below the mean.

Mean latencies to find the platform in phase 2 are presented in the middle panel of Figure 6.2. A 2 group x 12 trial mixed ANOVA on these data found significant main effects of group, *F* (1, 46) = 7.62, *MSE* = 178, *p* = .008, η_p^2 = .14, and trials, *F* (2, 99) =

25.30, *MSE* = 522, $p < .001$, $\eta_p^2 = .36$, and a Trials x Group interaction, *F* (2, 99) = 5.17, *MSE* = 522, $p = .006$, $\eta_p^2 = .10$ [Greenhouse-Geisser correction applied]. The group effect and the interactions with group reflect significantly longer latencies in the control group than the experimental group on trial 1 only, $t(28) = 2.8$, $p < .05$; the main effect of trials reflects a reduction in mean latencies overall as training progressed.

Mean latencies to find the platform in the test are presented in the right panel of Figure 6.2. Analysis of the first trial when any blocking effect would be expected to be maximal found no difference between groups, independent $t(46) < 1$, $p > .05$. A 2 group x 8 trial mixed ANOVA on the test phase latencies found a main effect of trials, *F* (1, 61) = 43.90, *MSE* = 2547, $p < .001$, $\eta_p^2 = .49$[Greenhouse-Geisser correction applied] , but neither the main effect of group, *F* (1, 46) = .234, *MSE* = 656, $p > .05$, $\eta_p^2 = .005$, nor the Trial x Group interaction, *F* (1, 61) = .1, *MSE* = 2547, $p > .05$, $\eta_p^2 = .002$ [Greenhouse-Geisser correction applied] , was statistically significant ($p > .05$).

In Experiment 8, blocking did not occur in a design that was identical to that of Experiments 5 and 6 except that no auxiliary shapes were presented in phase 1. This outcome is consistent with the hypothesis that a process of learning to ignore irrelevant shapes in phase 1 is a requirement for blocking of learning between shapes.

To a large extent, this outcome obviates the need to investigate the number of auxiliary shapes presented in phase 2. In Experiments 5 and 6, many compound-cues in phase 2 resulted in blocking (when phase 1 also contained many cues); but, in Experiment 8, an identical arrangement of compound-cues in phase 2 resulted in no blocking (when phase 1 had no extra cues). Thus, variations in blocking depend on phase 1 learning independently of phase 2 treatments.

It is interesting to note that the difference between groups at the outset of phase 1 in Experiment 3 was replicated in Experiment 8, consistent with further casual observations that when a T-shape is presented alone (for the control group), people tended to follow its ‘path’ which leads to target discovery more rapidly than when the triangle or irregular shape cues were presented to experimental group participants. This pattern on the first trial was not significant in Experiment 7, although a similar direction was apparent.

CHAPTER 7

GENERAL DISCUSSION

The aim of this thesis was to establish whether, or under what circumstances, cue-competition effects are found when people learn a location based on large-scale shapes. Specifically, 8 experiments investigated whether learning to use a large, asymmetric shape to locate a goal will reduce, or ‘block’, subsequent learning about an added landmark or shape that could also be used to find that goal, in accordance with established principles that have been proposed to govern associative learning. In Experiment 1, locating a goal in an irregular shaped enclosure was found to block learning about a landmark subsequently placed within its boundaries. Evidence from this and related experiments using identical stimuli and similar procedures (Wilson & Alexander, 2008) suggests that participants probably did not use the overall shape of the irregular enclosure in order to locate the goal. In subsequent experiments, the stimuli were 2D shapes presented horizontally on the ground, which ensured that overall shape was perceived on all trials. In Experiments 2 & 3, a few auxiliary cues were presented to act as control stimuli to ensure that only geometric properties could serve as location indicators. No evidence of blocking was apparent, and the direction of outcome was opposite to that anticipated from a blocking design. In Experiment 4 the demands of the task were increased by presenting additional separated auxiliary stimuli in each phase of learning with the aim of interfering with rational or rule-based learning processes that may have attenuated a blocking effect. While a direction consistent with blocking was found, the effect was not significant. In Experiment 5 when a concurrent arithmetic distracter task was introduced into the same procedure and the auxiliary cues were compounded in phase 2, a clear blocking effect was found. Experiment 6 was a replication of Experiment 5 but without the distracter task. A significant blocking effect was again found, demonstrating that the critical variable to a blocking outcome was the number of irrelevant shapes present during training, rather than the distracter task. One difference between Experiment 3 which found no blocking effect, and Experiments 5 and 6 which found blocking, was that only two shapes were present in the test in the former, whereas in the latter multiple shapes were used in the test. Therefore, Experiment 7 replicated the phases 1 and 2 training of Experiment 3, but presented participants with multiple auxiliary cues in the test. Consistent with Experiment 3, the outcome was the absence of blocking, which confirmed that, rather than the test conditions, the presence or absence of auxiliary stimuli during one or both training phases was the crucial variable in promoting blocking. Experiment 8 investigated this hypothesis further by presenting stimuli in phase 1 that were identical to those employed in Experiment 3 where a single shape was presented to participants. In phase 2 and the test phase the stimuli were identical to those used in Experiments 5 and 6. In Experiment 8 blocking was not found, an outcome consistent with the hypothesis that a process of discrimination learning in phase 1 is a requirement for blocking of learning between shapes (see Appendix Figure A 7.10 for a visual summary)

Evidence of blocking of goal location learning between large scale shapes A and B in Experiments 5 and 6 (and a non-significant direction consistent with blocking in Experiment 4) suggests that spatial learning is governed by the same error-correcting mechanisms that govern contingency learning. This outcome is contrary to accounts that propose a specialised status for geometric spatial learning (Cheng, 1986; Gallistel, 1990). The distinctive operation of an encapsulated geometric module is difficult to justify if shapes compete with each other as location indicators in the same way that cues compete with each other as potential causes of outcomes in other forms of contingency learning.

Blocking in Experiments 5 and 6 also undermines the more general hypothesis of a cognitive map that is governed by automatic or incidental learning processes. The theory of locale learning (O'Keefe & Nadel, 1978) proposes that during exploration all cues added to an environment are updated automatically within a cognitive map. The implication is that in spatial learning competition between cues should not be found.

The blocking outcome provides prima facie evidence that contradicts the geometric module and cognitive mapping theories. However, this interpretation is incomplete because blocking was only found when initial learning about shape-A was undertaken in the presence of auxiliary shapes. In Experiments 2, 3, 7 and 8 when learning about shape-A was initially carried out in the absence of auxiliary shapes, no blocking effect was found. The fundamental question is whether these failures to find blocking undermine the implications of the blocking effects established in Experiment 5 and 6.

The emergence of blocking in the current series depended on the presence of shapes that were anticipated to be essentially irrelevant to learning the goal location. When shape-A was initially trained alone, no blocking occurred, but when trained in the context of other shapes, blocking was found. According to established accounts of associative learning, blocking will occur in all cases where cues A and B consistently predict an outcome irrespective of auxiliary or irrelevant cues. This is because such cues should lose any associative strength that initially accrues to them, or they should quickly come to be ignored (Mackintosh, 1975; Rescorla & Wagner, 1972). It is reasonable to presume that an analysis of learning in terms of rational processes (see De Houwer & Beckers, 2002; Shanks, 2007), would suggest that where location cues are irrelevant for the solution of a problem they should also come to be ignored. It follows that the prediction from a rational learning account is that blocking should occur irrespective of the presence of auxiliary cues. Thus, neither the rational nor associative learning accounts of cue competition predict the findings in the current series of experiments where modulation of the blocking effect is dependent on the presence of auxiliary cues which were not the focus of learning. An alternative explanation is therefore required and perhaps this can be found in how learning to ignore stimuli generalises between phases.

The rationale of Experiment 8 was to test the hypothesis that learning to ignore all stimuli during phase 1 can generalise into a tendency to ignore all new cues added in subsequent training. According to an attention account (Mackintosh, 1975), if shape-A is initially trained in the presence of auxiliary shapes (the experimental groups of

Experiments 5 and 6), attention will increase to the relevant shape-A, and actively decline to ‘all irrelevant shapes’- the auxiliary cues. If this tendency to ignore all shapes (Mackintosh, 1975), that are not shape-A is carried forward to phase 2, efficient target localization will be maintained based on learning to shape-A. However, the tendency to ignore all shapes other than shape-A will cause a shift in attention that will ensure that shape-B will be ignored along with all new shapes or novel presentations of previously seen shapes. The failure to attend to shape-B in phase 2 will lead to blocking of location learning as seen in Experiments 5 and 6.

However, it is possible that a different process occurs when shape-A is trained without auxiliary shapes in phase 1 (in the experimental groups of Experiments 2, 3, and 8), where learning to actively ignore other shapes is not involved in target localization. When shape-B is presented in compound with shape-A in phase 2, rather than shape-B being ignored, it appears to be located in memory with respect to the geometric properties of shape-A. In the test, presumably shape-B invokes a memory of its former relative location to shape-A as well as the target location. The lack of cue competition under this arrangement is consistent with predictions from a locale or geometric account of spatial learning (O’Keefe & Nadel, 1978; Cheng, 1986). Shape-A is all that is required to locate the target, but its presence does not interfere with learning about shape-B because a tendency to ignore all irrelevant stimuli has not been transferred from phase 1 to phase 2. In fact, the direction of effect in Experiment 3 suggests that the initial training of shape-A alone, if anything, facilitates learning about shape-B. However, the effect was not significant, and therefore it would be inappropriate to offer an account of facilitation. It is worth noting that neither associative learning theories (Macintosh, 1975; Rescorla & Wagner, 1972), or locale or geometric theories (O’Keefe & Nadel, 1978; Cheng, 1986) predict enhanced learning about shape-B.

For the control groups in all experiments, shape-C must initially be used to locate the target in phase 1, regardless of whether auxiliary shapes are present (and regardless of whether these shapes come to be ignored). As shape-C is not presented in phase 2, the control groups must learn a new location by attending to the shape-AB configuration to find the platform. The difference for the control groups however, is that in phase 2 they will ignore all shapes other than the shape-AB configuration because they are learning about a new goal location with a novel arrangement of cues. Therefore, their primary processing resources are focussed on the most relevant predictor of the target location: shape-AB. In the test, shape-B will presumably invoke a memory of the shape-AB configuration from phase 2 and the associated target location.

A further issue that warrants consideration stems from the performance of the control groups in Experiments 2 to 8. For blocking to occur the control group must learn about shape-B to a greater extent than the experimental group in phase 2 training. One interpretation of the current results is that the control groups in Experiments 4,5, 7 and 8 learned little about shape-B as latencies at the outset of the test phase were longer than those at the beginning of phase 2 when it was first encountered. Furthermore, poor test performance in the experimental group could be due to a persistence in searching for the absent shape-A rather than blocking of learning about shape-B. However, it seems unlikely that participants would persist in their search for shape-A as it was immediately obvious when participants turned to face the environment that it was absent. In Experiments 4, 5, 7 and 8 there was a considerable difference between phase 2 and the test phase in terms of the number of shapes present. In phase 2, participants searched four compound shapes whereas in the test phase there were six individual shapes to search. It would be reasonable to expect therefore that in the absence of any knowledge about the goal, latencies would be longer in the test. Search latencies are therefore dependent on the parameters present in phase 2 and the test and thus the magnitude of the dependent variable effectively changes between phases. Given the change between phases, the most appropriate comparison from which to draw inferences about learning is between groups within the same phase rather than between phase comparisons. In addition to the increased number of shapes in the test, the arrangement of cues was also markedly different. In the test all cues were presented individually whereas phase 2 cues were presented in compound. The combination of increased number of shapes which were presented in a different configuration meant that in the test the control group search latencies were poor due to a large generalization decrement. The control group is however significantly faster to find the goal in the test indicating that they must have learned something in phase 2 to help them to locate the goal in the test. For the experimental group, nothing is learned about shape-B and search latencies in the test are comparable to those at the outset of phase 1. These long search latencies reflect that for experimental participants, the test is a relatively novel and complex environment that contains no cues for goal localization. Procedurally both groups had identical training and testing with shape-B but pretraining with shape-A in phase 1 for the experimental group reduced learning to shape-B compared to the control group.

The above account of why competition between shapes is sometimes found in location learning could have wider implications for the interpretation of spatial learning phenomena. Cue-competition effects emerged from the study of classical and instrumental conditioning procedures, mostly with non-human animals. These effects have typically been interpreted in terms of associative learning (e.g. Kamin, 1969). O’Keefe and Nadel (1978) proposed that locale learning differs from classical and instrumental conditioning, and by implication does not involve associative learning. As automatic updating of the cognitive map implies that cue-interactions should not occur in true spatial learning, the major debate in this area has sometimes been framed in terms of whether associative learning principles differ from spatial learning principles as inferred from cue-competition effects (e.g. Chamizo, 2003). The current demonstrations of cue competition between shapes suggest that this type of effect is common to both associative and true spatial learning; however, this need not imply that spatial and associative knowledge structures are the same.

In human contingency learning experiments, cue-competition effects have also been found, but these effects sometimes require more than associative learning for a complete account. Where effects conform to those in animal learning studies of classical and instrumental conditioning, an explanation in terms of associative learning seems to be appropriate. However, where human contingency learning leads to cue-interaction outcomes that differ in some respects from those found with animals, as when verbal instructions alone lead to an effect (e.g. Lopez, Cobos, and Cano, 2005), an appeal to higher order rational learning processes is sometimes more appropriate (see Shanks, 2007). From an associative perspective, learning should be automatic and impervious to top-down, cognitive influences, but as Shanks (2007, p 301) points out in his review of additivity and maximality in blocking studies '…participants try to figure out an underlying rational explanation of predictive roles'. It follows therefore, that the presence of cue-competition effects does not necessarily imply associative learning. In this respect it should be remembered that formal models that are traditionally invoked as accounts of associative learning (Mackintosh, 1975; Pearce, 1985, 1997; Pearce & Hall, 1980; Rescorla & Wagner, 1972) could equally be applied to other kinds of knowledge structure.

True spatial learning appears to depend on a knowledge structure that differs from both associative learning and rational learning. A cue that is associated with a target location may 'bring to mind' features at that location but this knowledge structure will not provide information about the direction toward that location. Similarly, if rational learning is to enable the explorer to reach a goal, directional information is sometimes required. Directional information when piloting can be characterised as vector knowledge, which involves the processing of at least one angle with respect to at least one landmark and the distance between the observer and the goal. Thus, cue-competition effects are sometimes found in studies that imply associative learning, in others that imply rational learning, and yet in others that imply true spatial or vector learning. It appears that the mechanism responsible for cue competition is not specific to a particular type of knowledge structure.

The present results suggest that changes in attention can govern whether or not blocking is found in the spatial domain. Attention changes have been suggested as the mechanism responsible for cue-competition effects in associative learning (Mackintosh, 1975). Therefore, one potential factor that governs cue-competition effects in a variety of circumstances might be what people attend to, irrespective of whether the task and underlying knowledge structure is spatial, associative, or rational. Mackintosh's (1975) theory predicts that when a new stimulus is added, as in phase 2 of the current experiments, conditioning proceeds normally on the first trial and blocking only emerges as attention to it diminishes on subsequent trials. (In contrast, the Rescorla-Wagner (1972) model implies that conditioning to a new stimulus on compound trials is attenuated from the outset). However, the Mackintosh model cannot account for the present results as it suggests that blocking should be found in all the shape-based experiments. Preliminary training will ensure that shape-A is attended to, and shape B actively ignored as a consequence, irrespective of auxiliary shapes in phase 1. A modified attention account based on 'grouping' all irrelevant cues in phase 1 can explain the pattern of results found in this thesis.

An important question is whether these variations on attentional theory make any new differential predictions. A 'one-trial blocking' design using the stimuli and general procedures of Experiments 5 and 6 (in which blocking was found) might help to further differentiate these attention-based accounts. If the effective change in attention following experience of multiple auxiliary shapes in phase 1 is a tendency for participants to ignore all new stimuli, this tendency should be in effect from the outset of phase 2. Thus, like the Rescorla-Wagner model, the modified attention account suggested in this thesis would predict blocking with only one trial in phase 2 of a blocking design that employed multiple auxiliary shapes in phase 1; Mackintosh's theory would predict the absence of blocking.

In summary, blocking of location learning between shapes as potential location indicators (Experiments 5 and 6) suggests that shapes can compete with each other under some circumstances, in a similar fashion to cues that serve as potential predictors of an outcome in contingency learning studies. This finding runs contrary to an account of true spatial or locale learning that appeals to specialised principles based on incidental or automatic learning of environmental cues. Furthermore it undermines the hypothesis of a specialised geometric module that is immune to cue competition.

The current series also produced failures to find evidence of blocking under only slightly altered circumstances (Experiments 2, 3, 7 and 8), which suggests compatibility with accounts of true spatial or locale learning that appeal to specialised learning principles. However, caution is required before assuming that the presence or absence of cue competition provides evidence for a particular knowledge structure. The current series of experiments illustrates how changes in attention might be a potential influence on the development of cue-interactions, irrespective of the underlying knowledge structure.

Implications of the present findings for recent additions to the literature

It is evident that in some circumstances, blocking of location learning can occur between large-scale shapes, and this might be accounted for in terms of the modulating effect of changes in attention. Following the conception of the series of experiments in this thesis, further research has suggested that there might be dual-mechanisms that operate in spatial learning according to the nature of the cues used for goal localization. Doeller and Burgess (2008) conducted experiments in VEs examining the relative processing of cues to a hidden goal location comprising distal boundary walls and local landmarks (cf. the present Experiment 1). They found asymmetric processing of cues in that a circular enclosure boundary wall overshadowed learning about a local landmark but a landmark failed to compete with learning about a boundary wall even when the salience of the landmark was substantially increased. The failure of the landmark to compete with the boundary wall is consistent with Redhead and Hamilton's (2007) experiments also using VEs. Doeller and Burgess (2008) propose that boundary walls are processed via automatic or incidental learning mechanisms which they characterise as "learning by observation", whereas landmark learning is subject to processes governed by associative learning mechanisms or "learning by doing". For Doeller and Burgess (2008), location learning based on boundaries operates in accordance with the suggestion that surface geometry is processed within a specialised geometric module (Cheng, 1986; Gallistel, 1990).

Experiment 1 (see also Wilson and Alexander, 2008) used VEs to investigate whether blocking could be found between the walls of an irregular four-sided enclosure and a local landmark presented within that enclosure. Wilson and Alexander (2008) also found an asymmetry in that learning about the enclosure walls led to strong blocking of the subsequently added local landmark, whereas the effect was significantly weaker when the landmark blocked learning about the enclosure walls. The weaker blocking effect was not influenced by an increase in the salience of the local landmark. While these findings are consistent with the asymmetry found by Doeller and Burgess (2008), Wilson and Alexander (2008) found significant blocking between a landmark and a boundary wall. This runs contrary to the dual-learning proposal of Doeller and Burgess (2008) that suggests different mechanisms operate for boundaries and landmarks. The privileged status for boundaries that they suggest implies that landmarks should fail to block learning about boundaries.

In both sets of experiments (Doeller & Burgess, 2008; Wilson & Alexander, 2008) the boundary could be used as a cue to the goal location. A possible reason for the difference in outcomes could lie in whether or not the overall boundary shape was used by participants to find the goal. Experiments with non-human animals indicate that there is little reason to believe that overall shape is used to locate a goal (e.g. Pearce et al, 2004). In humans however, the familiarity that arises from everyday exposure to symmetrical environments and taught geometry might lead to a more routine use of overall shape to locate a goal. In Doeller and Burgess' (2008) procedure, learning about the overall shape of the walled enclosure was not required to find the goal. It is likely however that human participants would recognise the circular shape formed by the boundary wall, as the circular wall was oriented using distal cues projected at infinity, and located the goal relative to the overall shape of the boundary. In Wilson and Alexander’s (2008) procedure, little evidence was found that learning about overall shape was the preferred method of locating the goal. Instead, 80% of participants reported learning about a single wall or corner rather than the overall shape of the enclosure to locate the goal. Thus the difference in cue-competition outcomes could result from participants in the Wilson and Alexander (2008) experiments using corners and/or walls as individual landmarks to locate the goal, while Doeller and Burgess’ (2008) participants used overall boundary shape. If the difference in these outcomes depends on whether overall shape was used (Doeller & Burgess, 2008) or not (Wilson & Alexander, 2008) then overall boundary shape rather than boundaries per se would be the factor implicated in determining immunity to cue competition. However, in Experiments 5 and 6 of this thesis, one large-scale shape was found to compete with another large-scale shape, undermining the hypothesis that location learning based on overall shape is necessarily immune to cue competition. The present results suggest that although the studies by Doeller and Burgess (2008) and Wilson and Alexander (2008) had different outcomes, this was not due to boundary-shape-learning being immune to cue competition. The present findings imply that, depending on circumstances, all aspects of spatial learning including shape, boundaries or landmarks can operate in accordance with mechanisms common to established associative learning mechanisms, and therefore be subject to cue competition.

The analysis above suggests that neither boundaries nor boundary-shape have a special status that influences whether blocking is found. The variations in blocking outcomes in the current series of experiments depended on whether auxiliary shapes were present during initial training. However, an alternative interpretation of the results that appeals to Doeller and Burgess' (2008) dual-learning hypothesis for boundaries and landmarks can be derived as follows: Blocking occurred in Experiments 5 and 6 when, during initial training, shape-A was presented among auxiliary shapes. In this context, shape-A could therefore be perceived as being one landmark among many others. When blocking was not found, in Experiments 2, 3, 7 and 8, shape-A was initially trained in isolation. Thus shape-A was perceived as the whole environment that was relevant to goal localization by reference to its boundaries. In accordance with Doeller and Burgess' (2008) hypothesis, the blocking outcome can be accounted for because landmarks can block landmarks in accordance with error-correcting learning mechanisms. The failure to find blocking can also be accounted for because boundaries are governed by incidental learning mechanisms and are immune to cue competition.

There are several problems with this interpretation; first, immunity of boundaries to blocking per se is not supported by the findings of Wilson and Alexander (2008) who, as already highlighted, found that learning about boundaries could be blocked by learning about a landmark. Second, the dual-learning hypothesis does not offer an account of what was learned in phase 2 training in the current series. In the second training phase, all participants in all experiments had to use the overall boundary of shape-A or B (or both) to locate the vertex that was closest to the hidden platform. At the same time, the auxiliary shapes that were present for all participants in phase 2 could have been perceived as alternative landmarks. Therefore, the goal location could have been learned in relation to the boundary of shape-AB while also being perceived as one landmark among other landmarks. Doeller and Burgess' (2008) account of different learning mechanisms for boundary and landmark learning does not predict which mechanism would be preferred in these circumstances. The present alternative to Doeller and Burgess (2008) account, based on the modulation of blocking due to attentional changes seems to offer a more parsimonious account of the current data.

The interpretation above suggests that a change in attention is the key factor that influenced whether blocking was found (Experiments 5 and 6) or not (Experiments 2, 3, 7 and 8). There is however a more general account that could explain the results without resort to a specific learning mechanism. For humans, in everyday learning situations, it is hard to imagine a scenario in which there is no requirement to make a discrimination between elements within the environment in order to decide which cues are the relevant predictors of a goal. A bland environment that does not include a variety of possible cues to a goal location would appear to be the exception in terms of the learning situations most commonly experienced by humans. More usually there is an initial stage in a new environment in which a discrimination has to be made between all of the available cues to determine which are relevant. In Experiments 2, 3, 7 and 8 learning initially took place in an environment in which only one cue predicted the goal location. Learning in phase 1 could therefore be considered to be unusual in these four experiments as these conditions are rarely encountered by humans in real-life situations. A more common scenario was encountered in Experiments 5 and 6 where multiple cues were presented and individuals had to make a discrimination to determine which cue was the relevant cue to goal location learning. The implication is that whenever an initial discrimination has to be made, whatever learning mechanism governs cue competition will be activated. The current demonstrations of spatial blocking can therefore be interpreted as the outcome that would most generally be anticipated because blocking occurred only when an initial discrimination between shape-A and the irrelevant cues was required. Conversely, the absence of blocking in Experiments 2, 3, 7 and 8, when initial training was in an otherwise bland environment can be interpreted as exceptional. The implication is that in situations where no discrimination is required in initial training then cue competition is less likely to be found.

This hypothesis appears however to be contradicted by the findings of Wilson and Alexander (2008, Experiment 2) who found that location learning based on a single 3D cross blocked learning about an irregular shaped enclosure. Given that initial location learning proceeded in the presence of a single cue alone, a prima facie interpretation might be that no discrimination was required. Therefore, this blocking result fails to accord with the hypothesis above, that a discrimination is required for cue competition. A closer examination of the nature of the cues might render this conclusion premature. In Wilson and Alexander’s experiment the cross was black on one side and grey on the other and the platform could only be efficiently located by discriminating between the two coloured aspects. In contrast, the geometric properties of the 2D shapes in the current series were presented and perceived in their entirety from the outset of training. When a shape was presented in isolation (Experiments 2, 3, 7 and 8) no discrimination was required other than from the background environment and no blocking was found. When shapes were presented as one among many, discrimination was required and blocking was found (Experiment 5 and 6).

The findings in this thesis highlight the importance of careful selection of stimuli that can be used as cues to goal localization in spatial learning experiments. In Experiment 1 participants indicated that they did not use overall shape to locate the hidden platform, making interpretation of the data difficult. The aim of using horizontally presented 2D shapes in Experiments 2 to 8 was twofold. Firstly, it allowed two shapes to be superimposed on each other while preserving their individual geometric characteristics. Secondly, it encouraged processing of overall shape because they were approached from a distal, external perspective. The analysis of phase 1 data showed that search latencies did not vary according to shape size, indicating that goal localization was based on overall shape perception. This change in methodology to 2D shapes allowed blocking between shapes to be investigated. Although conditions were found that promoted between-shape blocking it must be recognised that these findings may not generalise to experiments using walled enclosures in which overall shape cannot be readily perceived. While learning locations based on 2D shape may appear to be fundamentally different from learning about the continuous wall surfaces of an enclosure they may in fact both engage learning based on geometric properties. When piloting to find a hidden location with respect to enclosure walls, the same process is required, where vector learning is facilitated by the orientation of the walls. While the whole shape of an enclosure can be used to orient the observer in the same way as a 2D shape, a subset of the enclosure walls or corners can also provide sufficient information to aid goal localization. Whether whole shape or elements of shape are used, both involve processing of geometric information which orients the user. Learning about 2D shape may therefore be equated to learning about the continuous surfaces of enclosure walls.

Although this thesis has identified circumstances in which blocking occurs between shapes, it did not aim to investigate the precise form of spatial knowledge that is acquired during shape processing. In Experiment 2, localization of the goal was achieved by piloting with reference to the distal shapes A and B. One of the aims of moving the goal location close to the target cues in Experiments 3 to 8 was to encourage participants to find the goal specifically with reference to shapes A and B rather than the auxiliary cues. The change in procedure also meant that the goal could be localized by direct approach to the vertex adjacent to the goal. Different types of spatial information are normally hypothesised to underlie piloting and direct approach to a goal, with only the former reflecting geometric knowledge (e.g. Mackintosh, 2002). However, when overall shape forms the basis of goal-location learning, geometric knowledge might underlie the ability to locate a goal by both piloting and approach (see Figure 7.1). That is, to efficiently locate an invisible goal at a particular vertex of a shape, the overall geometric properties of that shape must guide the search in the same way that these properties must guide the search for a more distant goal when piloting. A prediction from this hypothesis is that the pattern of results reported in this thesis should be replicated when participants are required to pilot to find a goal rather than approach a region proximal to a particular vertex. A comparison between the results of Experiments 2 and 3 provides preliminary evidence that piloting and approach lead to similar outcomes. However, experiments that involve piloting in the presence of multiple auxiliary cues would require careful control procedures to ensure that piloting is based on only the target shape.

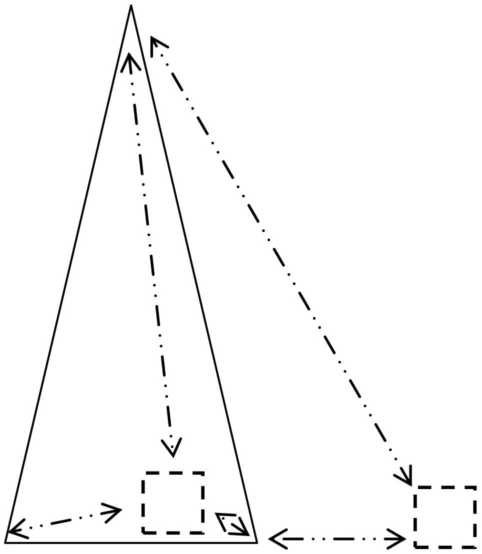

Figure 7.1 Piloting and approach to goal locations (dashed squares) with reference to a 2D target cue (isosceles triangle).

To summarise, blocking of location learning between shapes (Experiments 5 and 6) suggests that, at least under some circumstances, shapes can compete with each other in a similar fashion to the cues in other types of contingency learning studies. This finding is at odds with any account of spatial learning that appeals to automatic or incidental learning. However, for blocking to be evident the initially trained shape must be discriminated from other shapes prior to the introduction of the to-be-blocked shape. The hypothesis is that this arrangement provides the opportunity for participants to learn to ignore aspects of the environment that are not required to locate the goal, a strategy that remains active when the to-be-blocked shape is subsequently introduced.

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APPENDIX

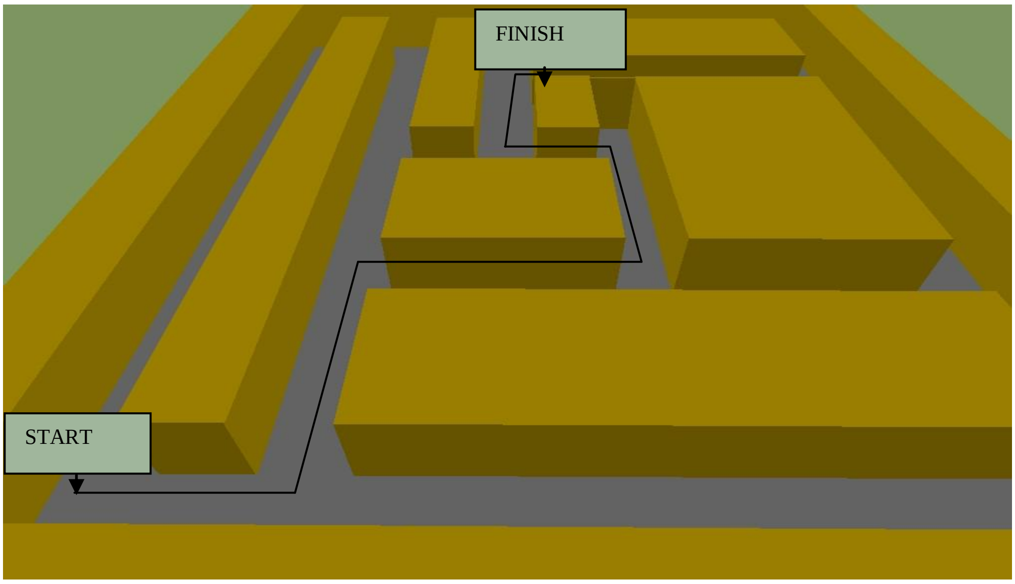

Figure A.7.1. Aerial view of the maze task for control participants instead of phase 1 training in Experiment 1. Participants had to find the correct route (marked in black) through the maze until they reached the finish point where they found an animated character. There was only one correct route and if incorrect pathways were chosen, invisible barriers blocked forward movement.

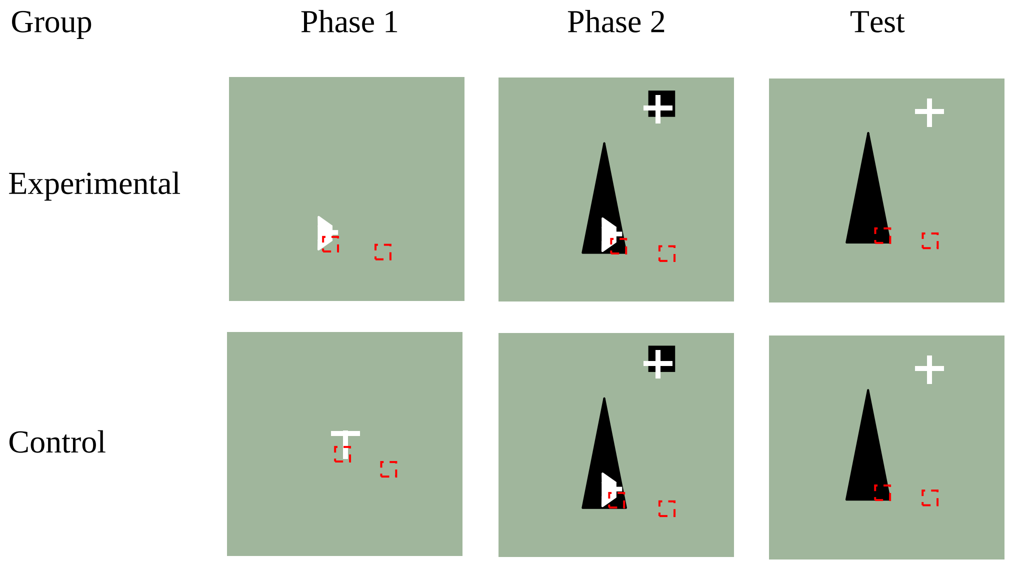

Figure A.7.2 The counterbalanced designs of Experiments 2 and 3. For the experimental group the irregular shape was presented in phase 1 and the large triangle was tested. The control group was presented with the small white T shape in phase 1. The platform location (indicated by the dashed red square) was close to the perimeter of the shapes in experiment 3 and a short distance away in Experiment 2.

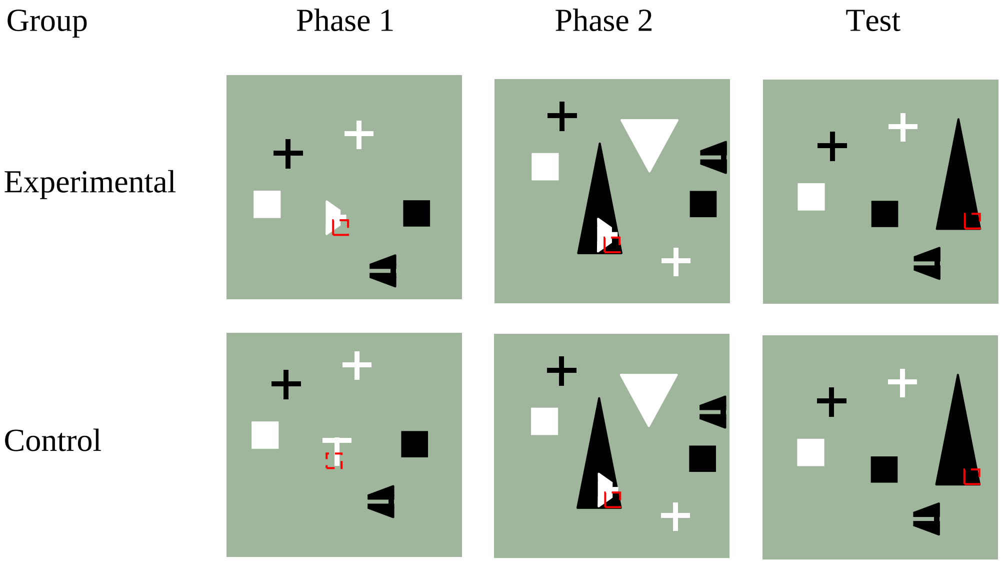

Figure A.7.3. The counterbalanced design of Experiment 4. For the experimental group the irregular shape was presented in phase 1 and the large triangle was tested. The control group was presented with the small white T shape in phase 1. The platform location is indicated by the dashed red square.

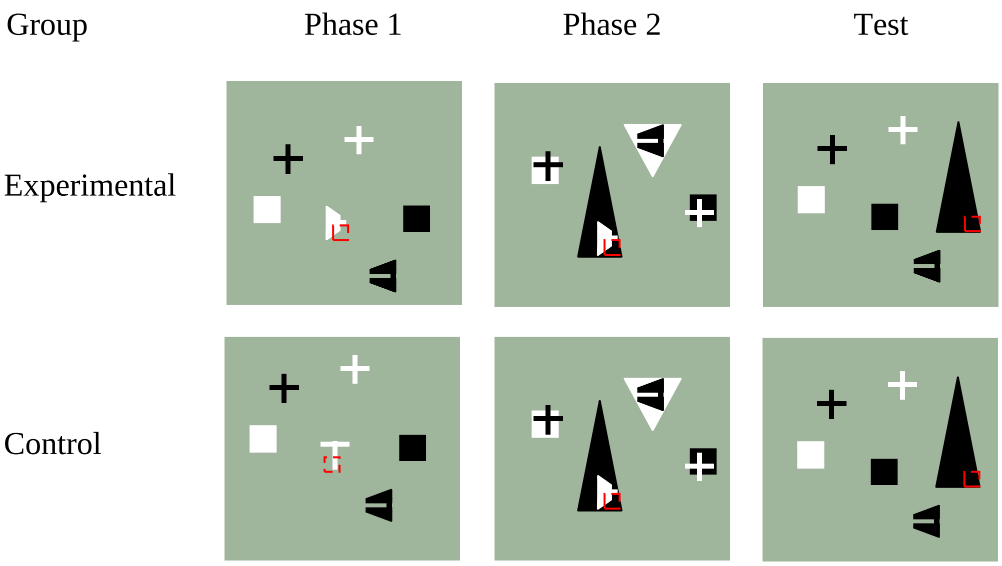

Figure A.7.4. The counterbalanced designs of Experiments 5 and 6. For the experimental group the irregular shape was presented in Phase 1 and the large triangle was tested. The control group was presented with the small white T shape in Phase 1. The platform location is indicated by the dashed red square.

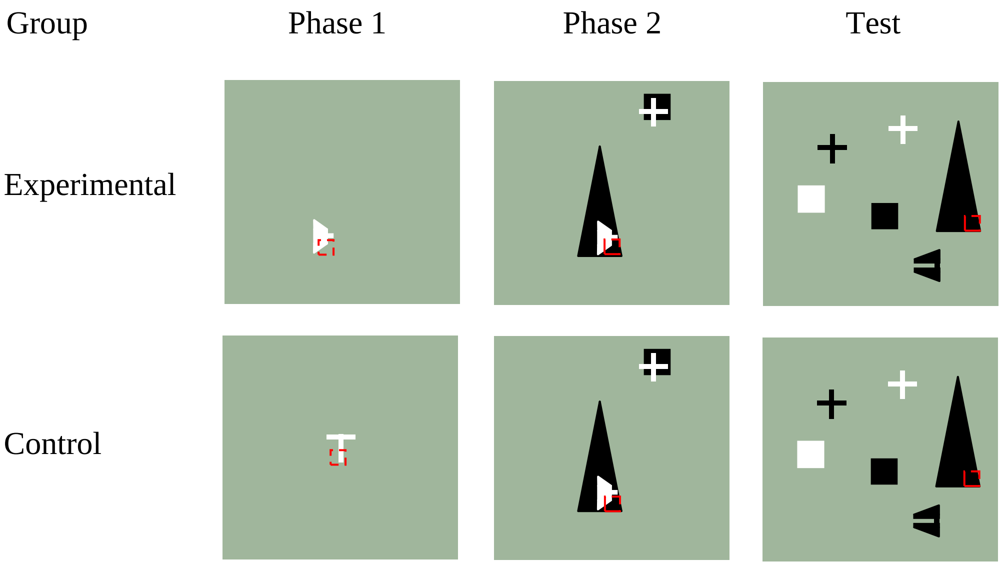

Figure A.7.5. The counterbalanced design of Experiment 7. For the experimental group the irregular shape was presented in phase 1 and the large triangle was tested. The control group was presented with the small white T shape in phase 1. The platform location is indicated by the dashed red square.

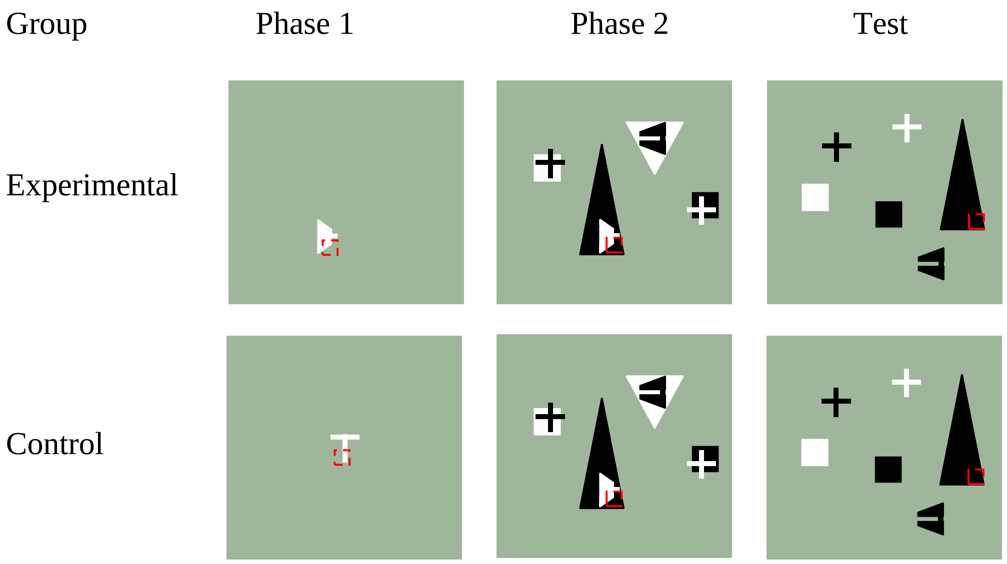

Figure A.7.6. The counterbalanced design of Experiment 8. For the experimental group the irregular shape was presented in phase 1 and the large triangle was tested. The control group was presented with the small white T shape in phase 1. The platform location is indicated by the dashed red square.

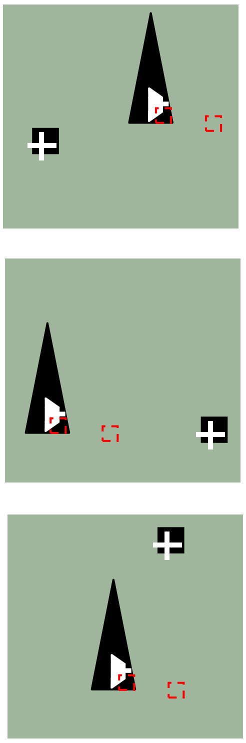

Figure A.7.7. The different arrangements of cues presented in phase 2 for Experiments 2, 3 and 7. Each arrangement was presented in blocks of four consecutive trials and the order of the changing arrangements was counterbalanced between participants in each group. This was to ensure that the non-target compound bore no consistent relationship to the platform location. The platform location is indicated by the red dashed square which was a short distance from the target compound AB in Experiment 2 and on its perimeter for Experiments 3 and 7.

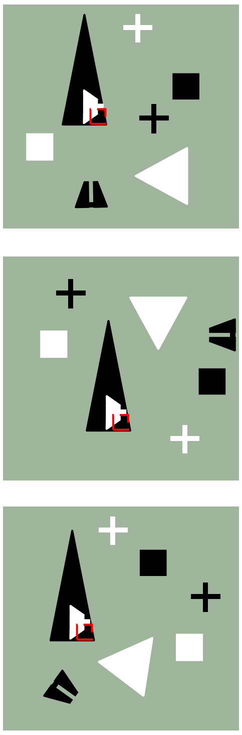

Figure A.7.8. The different arrangements of cues presented in phase 2 for Experiment 4. Each arrangement was presented in blocks of four consecutive trials and the order of the changing arrangements was counterbalanced between participants in each group. The platform location is indicated by the red dashed square.

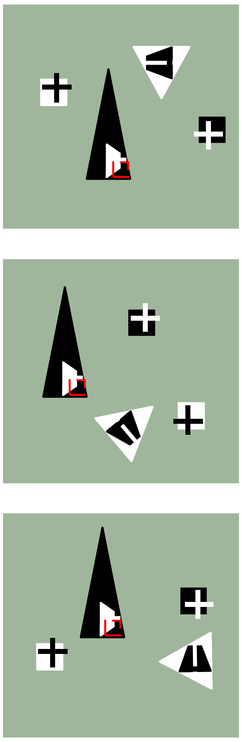

Figure A.7.9. The different arrangements of cues presented in phase 2 for Experiments 5,6 and 8. Each arrangement was presented in blocks of four consecutive trials and the order of the changing arrangements was counterbalanced between participants in each group. The platform location is indicated by the red dashed square.

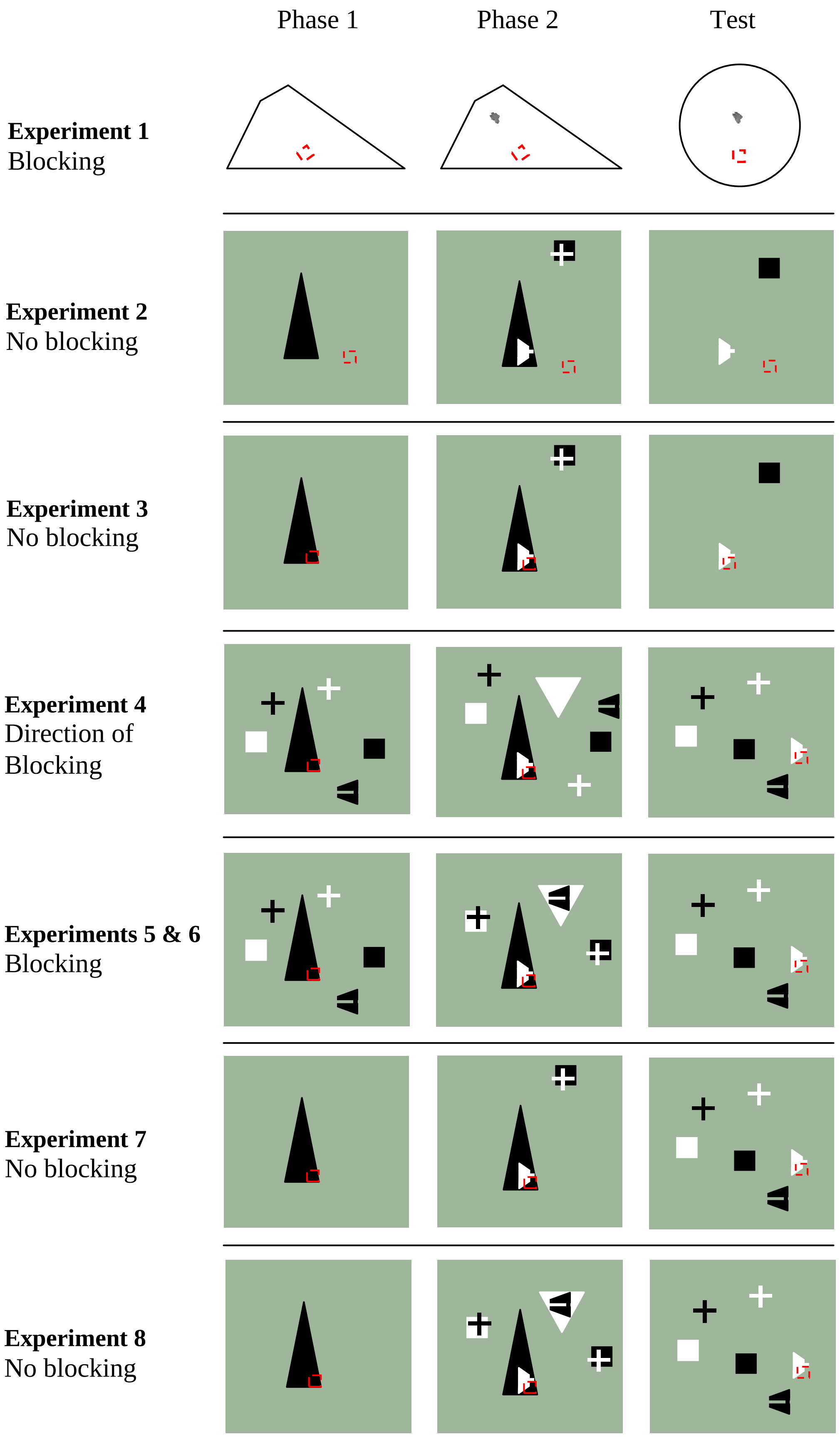

Figure A.7.10. Scale plan layouts of phase 1 , phase 2 and test phase for experimental groups in Experiments 1 to 8 showing the stimuli used for half of the participants where the black isosceles triangle acted as shape-A.