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Interaction between locale and taxon strategies in human spatial learning

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Abstract

Three computer-based experiments which tested human participants in a non-immersive virtual watermaze task sought to determine factors which dictate whether the presence of a visual platform disrupts locale learning and taxon learning. In Experiment 1, the visible platform disrupted locale but not taxon learning based on viewpoint-independent and viewpoint-dependent information, respectively. In Experiment 2, taxon learning based on non-geometric cues providing viewpoint-dependent information was disrupted by the visible platform when the cues required relational information to disambiguate them from other cues. Experiment 3 placed participants in an isosceles triangular pool. The presence of the visible platform did not disrupt the encoding of relational information provided by shape of the pool. These results support the notion that geometric cues are encoded in a separate module which is impenetrable to non-geometric cues not creating the shape of the environment.

Keywords: Virtual watermaze; Geometric cues; Taxon; Locale and Relational information

O'Keefe and Nadel (1978) propose that individuals use two fundamentally different strategies to navigate to a goal. A taxon strategy involves heading directly toward a landmark at or very near the goal. Alternatively, individuals may identify the position of, and navigate to, a goal with respect to an array of landmarks some distance from it but with a constant spatial relationship to it, a strategy described as locale learning. Nadel and Hardt (2004) suggest that

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the type of information used in taxon and locale strategies could, respectively, be considered viewpoint-dependent and viewpoint-independent. Evidence from neuropsychological experiments demonstrating the independence of these two strategies comes from numerous studies with both human and non-human participants (e.g., Feigenbaum & Morris, 2004; McDonald & White, 1995). Several behavioural studies have also explored whether learning one strategy disrupts the other or, as O'Keefe and Nadel (1978) suggested, both are learned in parallel. The studies have, however, produced outcomes that preclude any clear cut conclusions. For example, Bohbot, Iana, and Petrides (2004) demonstrated individual differences in the strategy used by human participants in a radial maze when both viewpoint-dependent and viewpoint-independent information were available: some participants used a locale strategy and others used a taxon strategy, and several participants switched strategies during the experiment. More analytic studies have attempted to establish the precise relationship between taxon and locale learning when opportunities for both forms are available.

Evidence of disruption to locale learning by the presence of a visible goal, allowing taxon learning, has been provided by both animal (e.g., Redhead, Roberts, Good, & Pearce, 1997) and human studies (e.g., Chamizo, Aznar-Casanova, & Artigas, 2003). Using a virtual watermaze depicted on a computer screen, Chamizo et al. (2003) demonstrated disruption of locale learning by the presence of a visible platform with humans. Participants were trained to use the arrow keys of the keyboard to navigate to a visible platform in the pool. The pool was surrounded by distal cues (a sphere, cone, cylinder, and cube), positioned at points North, South, East, and West just above the walls of the pool, such that they could be seen from all points within it. The platform was always placed between two of the distal cues. Thus, to reach the platform the participants could either simply scan the pool and move to it (taxon strategy) or learn the spatial relationship between the distal cues and the platform, then navigate to it in relation to these cues (locale strategy). To test what had been learned, the visible platform was removed during a test phase. The participants showed no evidence of having learned the spatial relationship between the position of the platform and the distal cues as they spent no longer than would be predicted by chance in the platform area. The presence of the visible platform had disrupted learning to use a locale strategy. Chamizo (2003) suggested that this demonstration of failure to learn the spatial relationship between landmarks and platform position was similar to overshadowing of a weak conditioned stimulus (CS) (e.g., a dim light) by a more salient CS (e.g., a loud tone) seen in associative learning experiments. In such circumstances, the tone acquires associative strength at the expense of the light (Mackintosh, 1976).

Disruption of locale learning by the presence of a visible goal has not always been demonstrated. Jacobs, Laurance, and Thomas (1997) showed a lack of overshadowing with humans in a computer-generated virtual watermaze similar to the one used by Chamizo et al. (2003). A visible platform did not disrupt learning about the position of the platform in relation to a rich array of distal cues such as doors, windows, and arches in the walls of the room in which the pool was placed.

Finally, there are animal studies demonstrating that locale learning is not disrupted by the presence of a visible beacon when the spatial cues are provided by the environment's shape (e.g., McGregor, Hayward, Pearce, & Good, 2004; Pearce, Good, Jones, & McGregor, 2004; Pearce, Ward-Robinson, Aydin, Good, & Fussell, 2001). Pearce et al. (2001) found that training rats to swim to a visible platform in a distinctively shaped pool did not disrupt the rats' ability to swim to the position of the platform when the visible platform was removed. Such evidence has lead to the claim that learning a locale strategy using geometric cues is impervious to disruption by non-geometric cues (Cheng, 1986; Gallistel, 1990; Margules & Gallistel, 1988).

The aim of the experiments in the current paper was to examine human spatial learning within a virtual watermaze where the position of the visible platform was also defined by distal cues. By systematically varying the spatial relationship between the visible platform and both non-geometric (in Experiments 1 and 2) and geometric distal cues (in Experiment 3), we hoped to gain an understanding of the circumstances under which learning a taxon strategy, based on the presence of a visible platform, disrupts learning of alternative taxon and locale strategies.

Experiment 1

One difference between the studies by Jacobs et al. (1997) and Chamizo et al. (2003) was that the former used more distal cues around the pool than the latter. The richer density of cues in the Jacobs et al.'s study meant that wherever the platform was placed in the pool it was in front of a distal cue providing viewpoint-dependent information for the position of the platform. This could have allowed a taxon strategy to be used with both the visible platform and distal cue. In the Chamizo et al. (2003) study, the platform was always placed between two cues, and thus the distal cues predominantly offered viewpoint-independent information requiring the development of a locale strategy. Taking the results of both the studies together, it might be possible to hypothesis that, on the one hand, the visible platform's presence does not disrupt a taxon strategy based on distal cues providing viewpoint-dependent information. On the other, it does disrupt the development of a locale strategy based on non-geometric distal cues which only provide viewpoint-independent information.

Experiment 1 was based on those reported by Chamizo et al. (2003) and Jacobs et al. (1997). A virtual watermaze task required participants to approach a visible platform to escape from a pool. The walls of the pool formed the shape of an equilateral triangle. One wall of the triangle was red while the other two walls were beige in color. The spatial relationship between the position of the visible platform and the red wall was constant throughout training. Participants could either locate the position of the platform by approaching the visible platform or by using the spatial relationship between the red wall and the position of the platform. The layout of the platform and pool can be seen in Fig. 1. In the test stage the visible platform was removed and the distance participants travelled in the platform area was recorded as an indication of how well they could use the landmark to locate the platform position.

Rather than use distal cues beyond the perimeter of the pool, the walls of the pool were used as non-geometric distal cues to make them as conspicuous as possible. The possibility that disruption of spatial learning occurred due to participants simply not noticing the distal cues was minimized. It should be noted that this manipulation does not rule out an attentional explanation based on Mackintosh's (1975) model, in which attention to the landmark would decline due to it being a poor predictor of the platform position compared to the visible platform. The use of colored walls as landmarks has been employed previously in both human (e.g., Hermer & Spelke, 1996; Hermer-Vazquez, Moffet, & Munkholm, 2001) and animal work (e.g., McGregor et al., 2004). Indeed Pearce, Graham, Good, Jones, and McGregor (2006) illustrated that a beacon attached to a platform which was placed in a corner created by two black walls did not disrupt encoding of the position

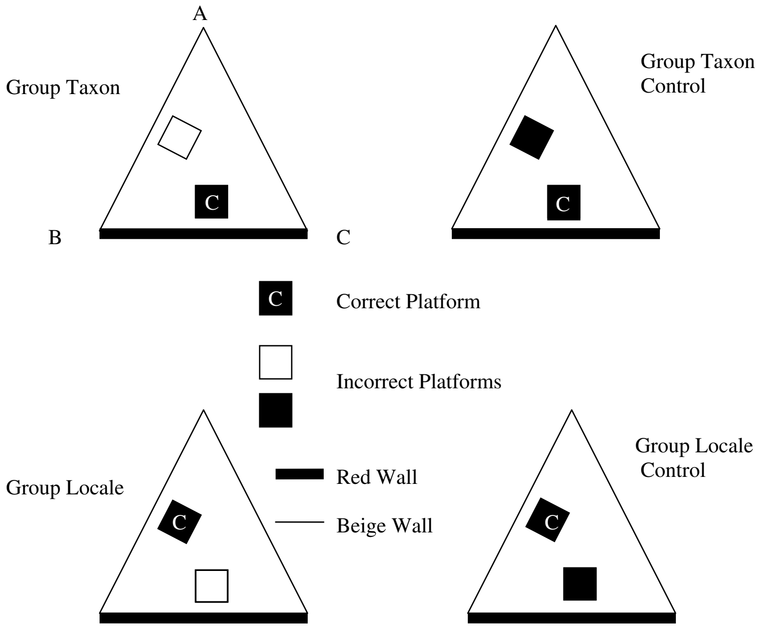

Fig. 1. Pool shape and platform position for Group Taxon, Group Taxon Control, Group Locale Control, and Group Locale.

of the platform in terms of the unique conjunction of black walls directly behind the platform. However, this is the first time that a colored wall has been used as a non-geometric distal cue within the virtual watermaze.

Experiment 1 examined whether approaching a visual platform disrupted taxon learning or locale learning. The platform was placed at the center of the red wall for Group Taxon providing viewpoint-dependent information regarding the position of the platform. Participants could learn to approach both the visible platform and the center of the red wall to navigate to the platform. A participant's view of the correct platform from the center of the pool can be seen in the upper panel of Fig. 2. For Group Locale, the platform was placed at the center of one of the beige walls either to the left or to the right of the red wall. Participants in this group could not view the orienting red wall when viewing the platform from the center of the pool. The view of the correct platform from the center of the pool for Group Locale can be seen in the lower panel of Fig. 2. The information provided by the red wall regarding the location of the platform was viewpoint-independent. Participants could only use a locale strategy if they were to use the red wall to locate the platform's position. When participants of either group reached the platform, the trial was terminated. A further platform was placed at the center of one of the other walls. This incorrect platform did not allow escape from the pool and was a different color from the correct platform.

During the test trial the platforms were removed and the distance participants travelled in the area of the platforms was recorded. A preference for the correct platform area was taken as an indication that the participants could use the red wall to locate the position of that platform. Based on the difference in results between the studies of Jacobs et al. (1997) and Chamizo et al. (2003), the presence of a visible platform was expected to disrupt locale

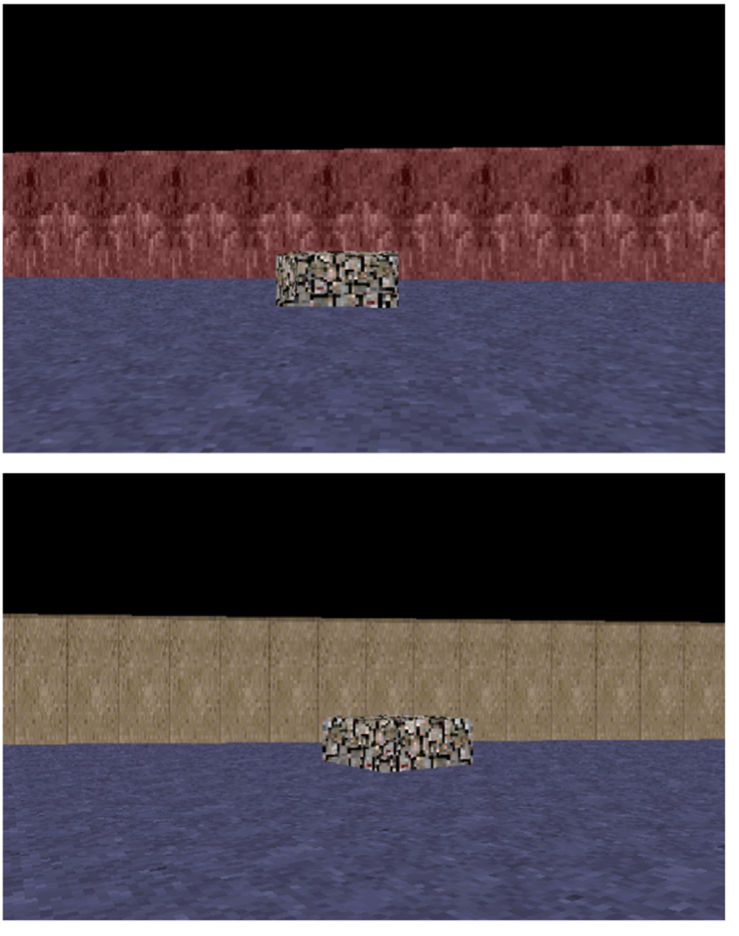

Fig. 2. Participant view of correct platform from center of pool in Group Taxon and Group Taxon Control (upper panel) and participant view of correct platform from the same position in Group Locale and Group Locale Control (lower panel).

learning but not taxon learning. Learning about the relationship between the landmark and the platform should be disrupted in Group Locale but not in Group Taxon.

Two control groups were included in order to compare the extent to which spatial learning was disrupted by the presence of the visible platform, Group Taxon Control and Group Locale Control. Both control groups received the same training as their respective experimental groups except that the two platforms were the same color. It was necessary for participants to use the position of the platform in the pool to identify the correct platform. In order to do this, participants had to learn the spatial relationship between the correct platform and the red wall. Removing the visible platform in these two groups should not disrupt the participants' ability to navigate to the platform area using the red wall.

Control groups with a platform which was not visible would also demonstrate the participant's ability to navigate to the platform using only the distal cues. Any difference between the control and experimental groups, however, may be due to factors other than disruption to locale or taxon learning. For instance, training to navigate to an invisible platform may encourage more persistence in the platform area during the test trial than learning to approach a visible platform. Control groups with identical visible platforms have been used previously by Redhead et al. (1997) and offer a better comparison for the experimental groups in Experiment 1.

Method

Participants

The participants were 40 undergraduate students receiving payment of £1.50 for participation. The mean age was 21.8 years (age range 18–32 years). Participants were divided equally into four groups, Group Locale contained 3 males and 7 females, Group Locale Control contained 4 males and 6 females, Group Taxon contained 3 males and 7 females, and Group Taxon Control contained 2 males and 8 females.

Materials and apparatus

The experiment was performed in a research cubicle (length 2.4 m, width 1.3 m, height 2 m) containing a chair in front of a 1.3 m wide work bench attached to the wall opposite the entrance to the cubicle. A 15 in. color computer monitor and keyboard were placed on the work bench. The monitor was connected to an IBM compatible PC placed beneath the bench.

The virtual environment consisted of a triangular pool. The triangle was equilateral with each wall 75 U in length and 15 U in height. Traversal of a virtual distance equal to the length of one of the walls in the equilateral triangle took approximately 4 s to complete. Two of the walls were beige in color and the other red. Two platforms were present during acquisition training. For Group Taxon and Group Locale, the correct platform was black and grey and the incorrect platform was white. For Group Taxon Control and Group Locale Control, both platforms were black and grey. Each platform was placed at the center of a wall, with one side of the platform parallel to the wall and at a distance of 3 U from the wall. Touching the correct platform terminated the trial. The visible platforms were cubes, 7 U in height, width, and length. For Group Taxon and Group Taxon Control, the correct platform was placed in front of the red wall. For half of Group Locale and half of Group Locale Control, the correct platform was placed in front of the wall to the right of the red wall, and for the rest the platform was at the center of the wall to the left of the red wall. An opaque, blue pattern was used to create the surface of the pool. Beyond the walls and above the pool, the background was black and no room contours were visible. The view on the screen from the center of the pool when the participant is facing the correct platform can be seen in Fig. 2. The upper panel depicts the view for groups Taxon and Taxon Control, where the correct platform is in front of the red wall. The lower panel illustrates the view for groups Locale and Locale Control, where the correct platform is positioned in front of one of the beige walls.

Auditory feedback consisted of a bell when the correct platform was reached, a discordant tone when the incorrect platform was touched, and the sound of moving water when forward motion in the pool occurred. Navigation was controlled using the keyboard arrow keys. The UP arrow key was used to control forward motion, and the LEFT and RIGHT keys controlled rotation. Backward navigation was not possible. In the absence of forward motion, it took 1.5 s to complete one complete rotation.

Procedure

Participants were led into the cubicle and asked to sit in front of the computer after which the experimenter left the room. The following instructions were given via the computer screen:

> In this experiment you will view a computer-generated environment on the monitor. You will be viewing the environment from a first-person perspective and you can move through the environment using the arrow keys on the keyboard (UP, LEFT, and RIGHT). You will be placed in a triangular pool of water from which you must escape by climbing onto a platform. When you touch the platform you will be stopped, raised out of the water, and you will see a message saying that you have found the platform. There will be two platforms in the pool, only one platform allows escape from the pool. Your goal is to locate that platform and climb onto it as quickly as possible. You will be on the platform for a few moments during which time you can scan around the pool. The screen will then fade out and you will begin another trial. You will complete several trials. On each trial you will begin facing the wall of the pool. Because you cannot move backwards you will need to turn before you can move out into the pool.
>
> Press the space bar when you are ready to start.

Once participants pressed the space bar, they were presented with a view of one of the corners of an equilateral triangle. Over the nine acquisition trials, each corner A, B and C was used three times. On reaching the correct platform, a bell sounded and the words "You have gained 10 points" appeared on the screen. The 10 points were added to a total displayed in the top right corner of the screen. Participants were then placed on top of the platform for 5 s before the screen went dark for 1 s, and participants were again placed facing a corner for the start of the next acquisition trial. If participants touched the incorrect platform, a discordant tone was sounded, the message "You have lost 10 points" was displayed on the screen, and 10 points were deducted from the total. The participants were allowed to continue each trial until they had reached the correct platform. The time to touch the correct platform was recorded for each acquisition trial. There were nine acquisition trials followed by a test trial in which the platforms were absent.

At the start of the test trial participants began in the center of the pool, facing corner A. They were not given any new instructions. There were no platforms in the pool, and the trial lasted for 45 s. The distance travelled in two circular areas of the pool was recorded. The areas were 5 U in radius and centered on the positions of the platforms during training. The total distance travelled in all parts of the pool during the test trial was also recorded.

Results and discussion

All statistical tests were evaluated with respect to an α value of 0.05. The group mean escape latencies over trials are displayed in the left hand panel of Fig. 3. They decreased over trials and Group Taxon appeared to have slightly longer latencies than the other groups. A three-way mixed design analysis of variance (ANOVA) was performed on the escape latencies, with whether the group was a taxon or locale strategy group (between), whether the group was experimental or control (between), and trials (within) as the

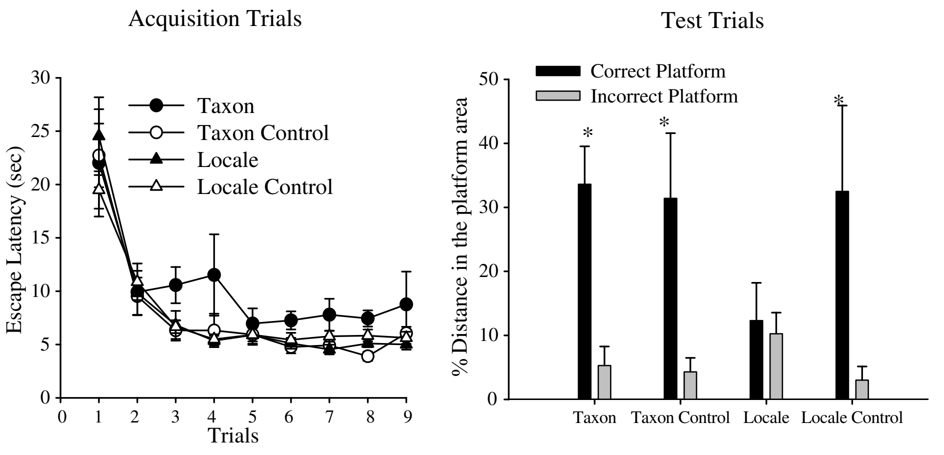

Fig. 3. Mean escape latencies during acquisition training for Group Taxon (filled circles), Group Taxon Control (empty circles), Group Locale (filled triangles), and Group Locale Control (empty triangles) (left hand panel). Mean percentage distance travelled in correct (black bars) and incorrect (grey bars) platform areas for Group Taxon, Group Taxon Control, Group Locale, and Group Locale Control during test trial (right hand panel). The standard error bars are the standard error of the mean. * denotes significant difference.

independent variables. There was no effect of strategy, $F(1,36) = 1.76$; there was no effect of experimental versus control, $F(1,36) = 2.42$; there was a significant effect of trial, $F(8,288) = 51.59$. There was no interaction between strategy and experimental versus control, $F(1,36) = 1.99$. There was no interaction between strategy and trial, or between experimental versus control and trial $F\text{s} < 1$. The three-way interaction was also not significant $F(8,288) = 1.25$.

The distance travelled in the platform areas was converted to a percentage of the total distance travelled during the test trial and the group means can be seen in the right hand panel of Fig. 3. There was a difference between the percentage distance travelled in the correct platform area compared to percentage travelled in the incorrect platform areas for Group Taxon, Group Taxon Control, and Group Locale Control but not for Group Locale. This group difference was confirmed via a three-way mixed design ANOVA performed on the percentage distance travelled with whether the group was a taxon or locale strategy (between), whether the group was experimental or control (between), and platform area type (within) as the independent variables. There was no effect of strategy, $F(1,36) = 1.81$, there was no effect of experimental versus control, $F < 1$, but there was a significant effect of platform area type, $F(1,36) = 39.19$. There was no interaction between strategy and experimental versus control, $F(1,36) = 1.76$. There was no interaction between strategy and platform area type, $F(1,36) = 2.92$, or between experimental versus control and platform area type, $F(1,36) = 3.49$. The three-way interaction was significant, $F(1,36) = 4.35$. Simple main effects analysis (Keppel, 1973) revealed that there was an effect of platform area type for Group Taxon, $F(1,36) = 16.75$, for Group Taxon Control, $F(1,36) = 15.02$, and for Group Locale Control, $F(1,36) = 18.09$, but not for Group Locale, $F < 1$.

Both control groups travelled more in the correct platform area than in the incorrect platform area during the test trial, illustrating that both control groups were able to use the red wall to locate the position of the platform. Of the experimental groups, only Group Taxon travelled more in the correct platform area than the incorrect platform area. It is possible to conclude that the presence of a visible platform disrupted locale learning more than taxon learning.

Group Locale could employ a locale strategy by learning the spatial relationship between the platform and the red wall. The participants could also employ a taxon strategy by learning to approach the visible platform. The results from the test trial suggest that they only learned to use a taxon strategy. When the visible platform was removed, participants travelled as much in the incorrect platform area as in the correct platform area. Group Taxon, on the other hand, could employ a taxon strategy using the viewpoint-dependent information from both the visible platform and the red wall directly behind the platform. The results suggest that the participants in this group used both sources of information. When the visible platform was removed, they spent more time in the correct platform area than in the incorrect platform area.

The suggestion that Group Locale Control was using a different strategy from the other groups to locate the visible platform was not supported by the escape latencies. There was no difference between the groups using this measure. It may be that there is no difference in the ease of learning a locale or taxon strategy. Alternatively escape latencies may not the best measure for determining a difference in strategy during acquisition in the current task given the small distance between the two platforms. Graham, Good, McGregor, and Pearce (2006) used the number of times the incorrect corner was chosen first as a measure of performance during training. In Experiment 2, this was measured for each participant.

The results of Group Taxon are relevant to the findings of Jacobs et al. (1997). The virtual environment used in the Jacobs et al. study provided a large number of non-geometric distal cues around the pool. Some of these distal cues could have provided viewpoint-dependent information on which to base a taxon strategy. If taxon learning is not disrupted by the presence of a visible platform it is not surprising that participants were still able to navigate to the platform position using only the distal cues. In Chamizo et al.'s study (2003), the platform was always placed between two of the non-geometric distal cues, and individual distal cues only offered viewpoint-independent information. The participants could only use individual distal cues as a basis for a locale strategy. The results of Group Locale suggest locale learning was disrupted by the visible platform and suggest it is not surprising that participants in the Chamizo et al. study could not navigate to the position of the platform in the absence of the visible platform.

In the introduction to Experiment 1, we suggested that participants were using a locale strategy to locate the platform in relation to individual distal cues in the study by Chamizo et al. (2003). It is possible, however, for the participants to have been using a taxon strategy based on the conjunction of two distal cues. For example, participants could have learned to head toward a view on the computer screen where the background was on the left and a specific distal cue was on the right. If this was the case, then the results of the Chamizo et al. study suggest that a visible beacon can disrupt a taxon strategy which is based on relational information. In order for the participants in the Chamizo et al. study to use a taxon strategy to locate the platform they would have to discriminate a view on the screen associated with the platform position from the view where the distal cue was on the left of the screen and the background on the right. Experiment 2 examined whether the presence of a visual platform disrupts learning a taxon strategy based on viewpoint-dependent information which requires relational information to disambiguate it from alternative distal cues.

Experiment 2

Two groups were examined in Experiment 2, Group Relational and Group Relational Control. Both groups were placed in an arena shaped like an equilateral triangle, with one red and two beige walls, and containing two platforms placed in the corners of the triangle. Participants were instructed to locate the correct platform which allowed escape from the pool. For half of the participants, the correct platform was in the corner to the right of the red wall and for the others it was in the corner to the left of the red wall. For the participants of Group Relational, the correct platform was black and grey and the incorrect platform was white. For Group Relational Control, the platforms were both black and grey and the participants had to use the spatial relationship between the distal cues and the platforms to identify the correct platform. The layout of the pools and position of the platforms can be seen in Fig. 4. The view of the correct and incorrect platforms a Group Relational participant would receive from the center of the pool can be seen in the upper and lower panels, respectively, of Fig. 5.

If the presence of the visible platform only disrupts locale learning, then Group Relational should spend more time in the correct platform area than the incorrect platform area as the distal cues provide an unambiguous cue next to the platform position and allow a taxon strategy to be employed. It is necessary for Group Relational to encode relational information in order to discriminate between the corner to the right of the red wall and the corner to the left of the red wall. If the presence of the visible platform disrupts learning about such relational information, then Group Relational should show poor spatial learning when the visible platforms are removed. The number of training trials was increased to 21 to ensure that participants had sufficient trials to learn the relational task.

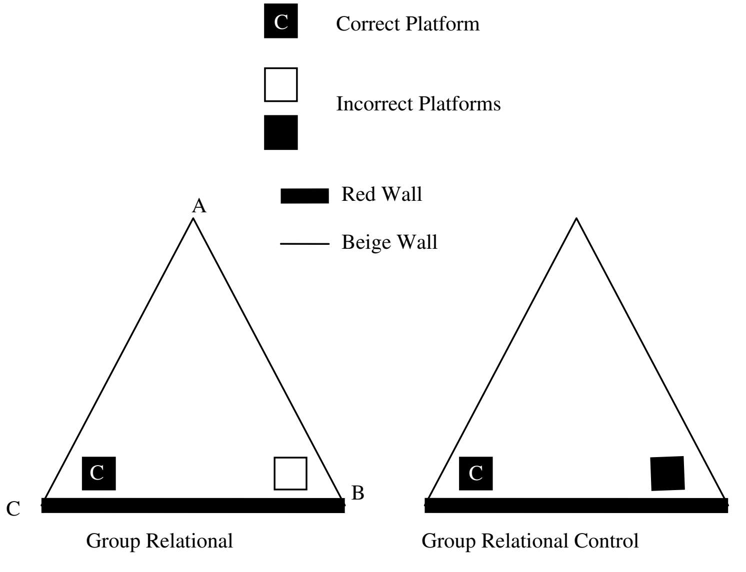

Fig. 4. Pool shape and platform position for Group Relational and Group Relational Control.

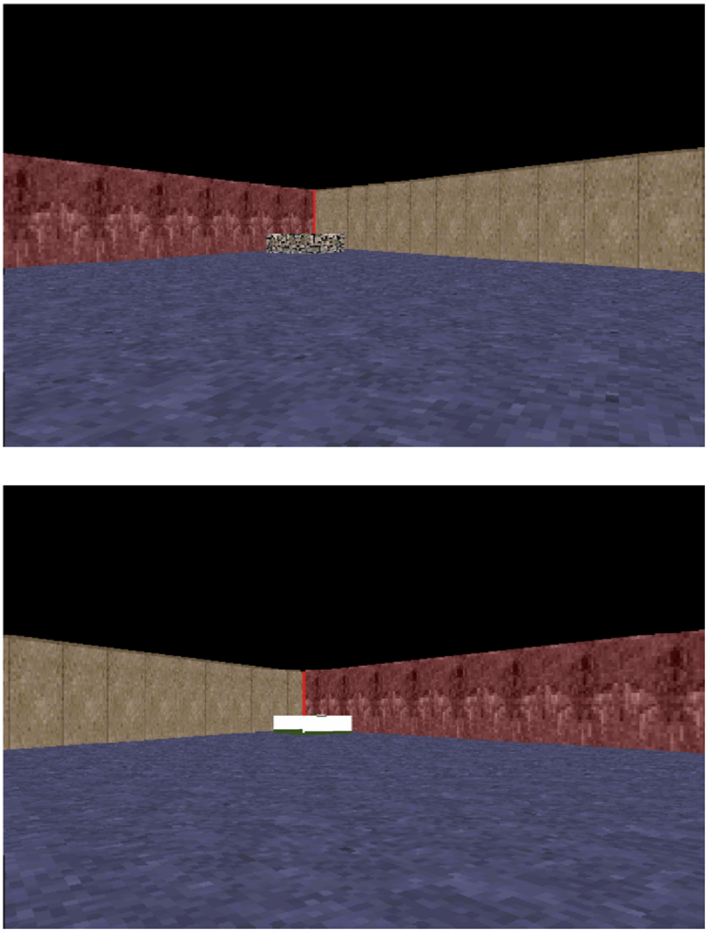

Fig. 5. View of correct platform (upper panel) and incorrect platform (lower panel) from center of pool for half of the participants in Group Relational.

Method

Participants

Participants were 32 undergraduate students, who received payment of £1.50 for participation. They were divided equally into two groups: Group Relational and Group Relational Control. Within each group, there were 6 males and 10 females. The mean age was 23.6 years (range 18–29 years).

Materials and apparatus

Materials and apparatus were the same as in Experiment 1, with the exception that the centers of the platforms were located 7 U on a line bisecting the corners B and C on each side of the red wall, with one of the sides of the platform parallel to the red wall. For half of the participants of each group, the correct platform was in corner B, and, for the remaining participants, the correct platform was in corner C.

Procedure

Participants were instructed to approach the correct platform over 21 acquisition trials. The number of occasions in which the incorrect platform was approached before the correct platform was recorded during training. All other procedural details were the same as in Experiment 1.

Results and discussion

All statistical tests were evaluated with respect to an α value of 0.05. The group mean escape latencies over trials for the groups are displayed in the left hand panel of Fig. 6. The escape latencies of Group Relational Control appear initially to be slightly longer than those of Group Relational, but this impression was not confirmed by the two-way mixed design ANOVA which was performed on the escape latencies with group (between) and trial (within) as independent variables. There was no effect of group, $F < 1$; there was a significant effect of trial, $F(20, 600) = 16.52$; there was no interaction between group and trial, $F < 1$. The group mean scores for the number of times the incorrect platform was approached first over the course of training was larger for Group Relational Control ($M = 5.25$, $SD = 3.36$) than for Group Relational ($M = 2.25$, $SD = 1.42$). An independent samples t-test confirmed that this difference was significant, $t(30) = 2.78$.

The group means for the percentage distance travelled in the correct and incorrect platform area during the test trial are displayed in the right hand panel of Fig. 6. Only Group Relational Control demonstrates a difference between the percentage distance travelled in the two platform areas. This impression was confirmed by a two-way mixed design ANOVA performed on the percentage distance travelled with group (between) and platform area type (within) the independent variables. There was no main effect of group, $F < 1$, there was a main effect of platform area type, $F(1, 30) = 7.32$, and there was a significant interaction between group and platform area type, $F(1, 30) = 6.43$. Further analysis of the simple main effects revealed that there was no effect of platform area type for Group Relational, $F < 1$, but there was an effect of platform area type for Group Relational Control,

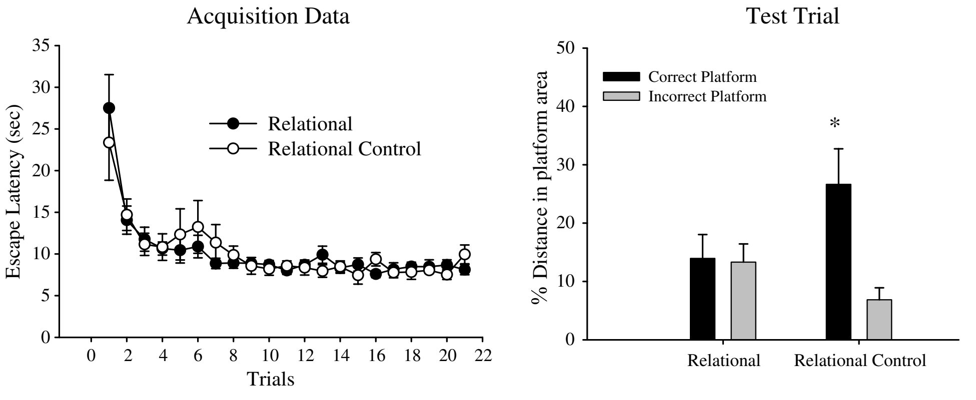

Fig. 6. Mean escape latencies during acquisition training for Group Relational (filled circles), Group Relational Control (empty circles) (left hand panel). Mean percentage distance travelled in correct (black bars) and incorrect (grey bars) platform areas for Group Relational and Group Relational Control during test trial (right hand panel). The standard error bars are the standard error of the mean. * denotes significant difference.

$F(1,30) = 13.73$. There was a significant effect of group for the correct platform area, $F(1,60) = 5.09$ but not for the incorrect platform area, $F(1,60) = 1.31$.

The main finding from Experiment 2 was that for participants in Group Relational there was no difference in the distance travelled in the correct and incorrect platform area. This was in comparison to Group Relational Control participants who had to pay attention to the spatial relationship of the walls and platforms to differentiate between the platforms. This group showed a difference in distance travelled in the correct and incorrect platform area. Group Relational Control participants also travelled more in the correct platform area than Group Relational, but there was no difference in the amount each group travelled in the incorrect area. It would appear that the presence of the visual platform disrupted a taxon strategy based on a non-geometric distal cue and provided viewpoint-dependent information requiring relational information to disambiguate it from other non-geometric distal cues.

Given that the participants of Group Relational Control were required to learn the relational information provided by the walls of the pool to differentiate the platforms it was again surprising that there was no difference between the escape latencies of the two groups. The additional measure of performance during training recorded in Experiment 2 did reveal a difference between the groups. Group Relational Control chose the incorrect platform on more trials than the participants of Group Relational. This finding suggests that relational learning is more difficult than the simple visual discrimination required in Group Relational and may explain why Group Relational participants only encode the simpler visual discrimination.

Results from Experiments 1 and 2 suggest that a visible platform can disrupt both locale and taxon learning based on the spatial relationship of non-geometric landmarks. However, as stated in the introduction, there has been a series of experiments demonstrating that learning about the spatial relationship of surfaces surrounding a goal constituting the environment's shape is not disrupted by non-geometric cues (for review see Cheng & Newcombe, 2005). Experiment 3 presented an environment which offered spatial cues based on its shape in order to examine whether learning about the spatial relationship of these geometric cues was disrupted by the presence of a visible goal in the virtual watermaze with human participants.

Experiment 3

There were three groups in Experiment 3. For all groups, the pool was an isosceles triangle and its shape could be used to locate the position of the platform. Each group had two platforms placed in the corners on each side of the shortest of the three walls, and only one platform allowed escape from the pool. For a layout of the pool and platforms, see Fig. 7. The participants learned to approach the correct platform over 21 training trials. On the test trial, the platforms were removed and the percentage distance travelled in the platform areas was recorded.

Group Shape was the equivalent to Group Relational in Experiment 2. Both groups had a set of distal cues which required relational information to discriminate from other distal cues. In order to escape the pool, the participants of Group Shape could approach the black and grey platform or approach the corner where the long wall was for half of the participants to the right of the short wall, and for the other half, to the left of the short wall. Fig. 8 provides a

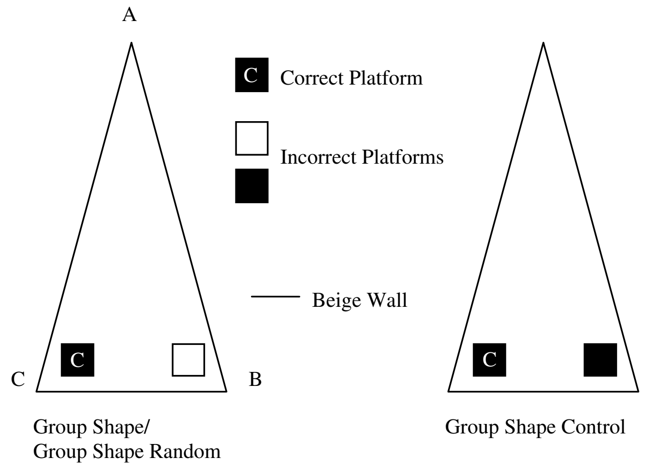

Fig. 7. Pool shape and platform position for Groups Shape/Shape Random and Group Shape Control.

participant view of both platform types from the center of the pool. From Experiment 2, it might be expected that, as with Group Relational, Group Shape would show evidence of poor spatial learning in the test trial. If learning to approach a visible platform does not disrupt learning about the position of the platform in terms of the geometric cues, as has been found in previous studies (e.g., Pearce et al., 2001), it might be expected that the participants in Group Shape would show good spatial learning in the test trial.

Group Shape Control received the same training as Group Shape except that the platforms were both black and grey. Participants could only identify the correct platform from its position in the pool. Removing the visible platforms for the final test trial should not affect participants' ability to use the shape of the pool to navigate to the correct platform area. If both Group Shape and Group Shape Control showed a preference for the correct platform, a further control group was required to illustrate that the preference was not due to a random bias caused by an uncontrolled artefact. For the third group, Group Shape Random, the correct platform was black and grey and the incorrect white. The positions of the correct and incorrect platforms were alternated between the corners on each side of the short wall from trial to trial. Group Shape Random should show no preference for either of the corners.

Method

Participants

The participants were 36 undergraduate students, receiving payment of £1.50 for participation, and were divided equally into three groups: Group Shape, Group Shape Control, and Group Shape Random. Within each group, there were 3 males and 9 females. The mean age was 23.8 years (range 18–36 years).

Materials and apparatus

Materials and apparatus were the same as in Experiment 1 with the exception that the pool was an isosceles triangle with the long walls 130 U in length and the short wall 50 U.

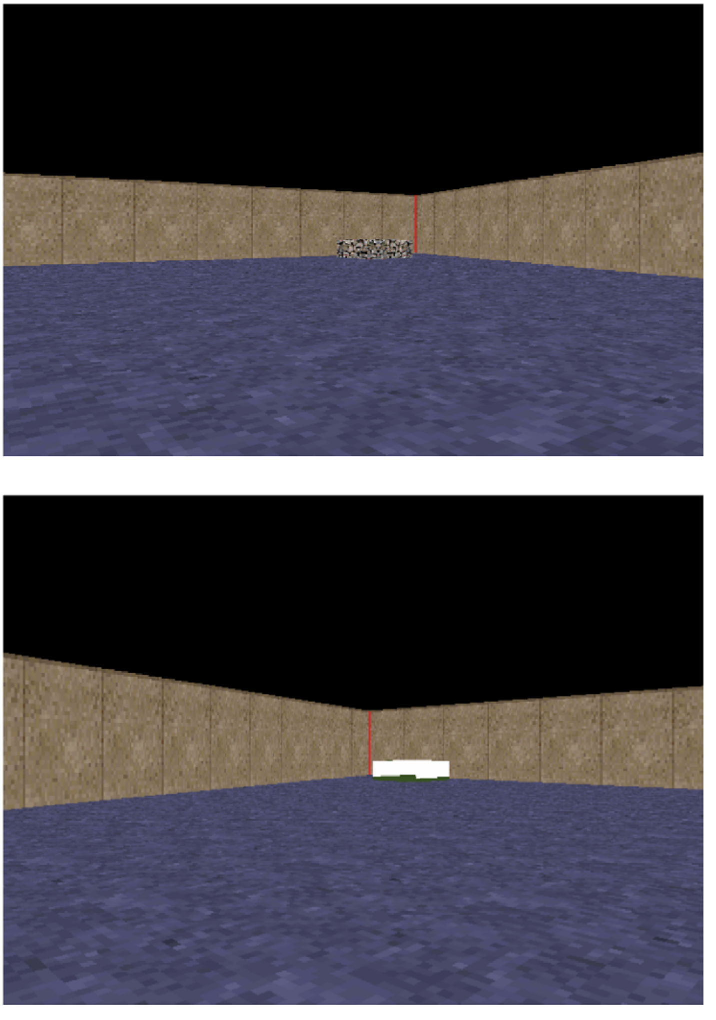

Fig. 8. View of correct platform (upper panel) and incorrect platform (lower panel) from center of pool for half of the participants in Group Shape.

It took approximately 6 s to travel the length of one of the long walls and 2.5 s to travel the length of the short wall. All walls were beige in color and 15 U in height. The centers of the platforms were located 7 U on a line bisecting corners B and C on each side of the short wall, with one side of the platforms parallel with the short wall.

Procedure

There were 21 acquisition trials in which participants started in one of the three corners of the triangle. Over the trials each corner was used seven times. The participants had to swim to and touch the correct platform. The platforms were in corners B and C on either side of the short wall. For all groups the correct platform was black and grey. For Group Shape Control, the incorrect platform was also black and grey, but for the Groups Shape and Shape Random, the incorrect platform was white. For Group Shape and Group Shape

Control, the correct platform remained in the same corner throughout acquisition; for half of these participants, the correct platform was in corner B and for the rest the platform was in corner C. For the participants in Group Shape Random, the position of the incorrect and correct platform alternated between these corners from trial to trial. All other procedural details were the same as for Experiment 1.

Results and discussion

All statistical tests were evaluated with respect to an α value of 0.05. Acquisition data for the groups are illustrated in the left hand panel of Fig. 9. The escape latencies for all three groups decreased over the training trials. The acquisition data were analyzed with a two-way mixed design ANOVA performed on the escape latencies with group (between) and trial (within) as the independent variables. There was no main effect of group, $F<1$, a significant effect of trial, $F(20, 660) = 16.41$, and no interaction between group and trial, $F(40, 660) = 1.02$.

The group mean scores for the number of times the incorrect platform was approached first over the course of training were similar for all three groups (Group Shape Control: $M = 2.50$, $SD = 1.45$; Group Shape: $M = 2.17$, $SD = 2.59$; Group Shape Random: $M = 1.67$, $SD = 1.07$). A one-way ANOVA was performed on the number of trials in which the incorrect platform was approached first during the course of training with group (between) the independent variable. There was found to be no effect of group, $F<1$.

The group means for percentage distance travelled in the platform areas during the test trial can be seen in the right hand panel of Fig. 9. There is a preference for the correct platform area over the incorrect platform area type in Group Shape and Group Shape Control but not in Group Shape Random. This impression was confirmed by a mixed design two-way ANOVA performed on the percentage distance travelled in the platform areas with

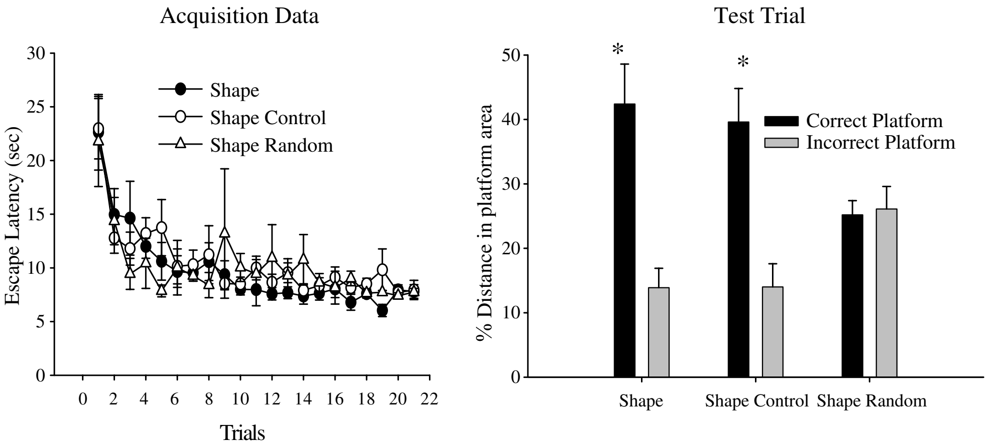

Fig. 9. Mean escape latencies during acquisition training for Group Shape (filled circle), Group Shape Control (empty circle), and Group Shape Random (empty triangle) (left hand panel). Mean percentage distance travelled in correct (black bars) and incorrect (grey bars) platform areas for Group Shape, Group Shape Control, and Group Shape Random during test trial (right hand panel). The standard error bars are the standard error of the mean. * denotes significant difference.

group (between) and platform area type (within) as the independent variables. There was no effect of group, $F < 1$, a significant effect of platform area type, $F(1, 33) = 24.22$, and a significant interaction between group and platform area type, $F(2, 33) = 6.76$. Simple main effect analyses (Keppel, 1973) indicated that there was a significant effect of platform area type for Group Shape, $F(1, 33) = 20.82$, and Group Shape Control, $F(1, 33) = 16.88$, but no effect of platform area type for Group Shape Random, $F < 1$. There was a significant difference between the groups for the percentage distance travelled in the correct platform area, $F(2, 66) = 5.27$, but not for the percentage difference travelled in the incorrect platform area $F(2, 66) = 3.06$. Further analysis of the distance travelled in the correct platform area, via a Newman–Keuls test, revealed that both Group Shape and Group Shape Control had a higher percentage distance travelled score in this area than Group Shape Random, q^{nk} (66) >3.58.

From the similarity in mean group escape latencies and mean group number of times the incorrect platform was visited it would appear that learning the position of the platform in terms of the shape of the environment was learned as quickly as learning to head toward a distinctively colored platform. This is in contrast to the findings of Kelly and Spetch (2004) who found that non-geometric information was encoded by human participants more quickly than geometric information when locating a hidden object. Kelly and Spetch presented their participants with a schematic view from above of a rectangular environment. Possibly the difference between the first person perspective of the scenes presented in the current study and the third person perspective presented in the Kelly and Spetch study accounts for the differences in the results observed.

The important finding from Experiment 3 was that participants in Group Shape travelled more in the correct platform area than in the incorrect platform area and that there was no difference between the results of Group Shape and Group Shape Control. Training with a visual platform did not disrupt learning about the relational information provided by geometric cues regarding the position of the correct platform. Participants in Group Shape Random showed no preference for either corner, suggesting that the preference seen in the other groups was not due a random bias caused by an uncontrolled artefact.

Experiment 2 illustrated that encoding non-geometric, viewpoint-dependent relational information was disrupted by the visible platform. However, from Fig. 8, it could be argued that the information provided by the geometry was not viewpoint-dependent. To be able to ascertain in which corner a long wall was to the right of the short wall, the participant would have to scan around the pool comparing the relative lengths of walls. Therefore, in terms of taxon and locale learning, the type of strategy demonstrated by Group Shape is much more akin to locale learning and so we are left to conclude that a visible beacon does not disrupt locale learning in a distinctive shaped arena.

General discussion

Experiment 1 demonstrated that a visible platform disrupted locale learning based on viewpoint-independent information. A taxon strategy utilizing viewpoint-dependent information, however, was not disrupted by the presence of the visible platform. Experiment 2 demonstrated that the visible platform did disrupt a taxon strategy based on viewpoint-dependent information provided by non-geometric distal cues which required relational information to disambiguate it from alternative cues. Finally, Experiment 3 demonstrated that the visible platform did not disrupt the use of geometric cues even though the geometric cues again required relational information to disambiguate them from alternative cues. There are several possible explanations for these results which require discussion.

O'Keefe and Nadel (1978) suggested two distinct navigation strategies, taxon and locale learning, and that locale learning, involved in the construction of a cognitive map, was not disrupted by taxon learning. The results of Experiment 1, however, suggest that if participants can employ a simple taxon strategy they will do so at the expense of the more complex locale strategy. Such an analysis fits well with the results of Chamizo et al. (2003). It also fits with animal work; for example, Redhead et al. (1997) found that a large visible beacon attached to the platform and clearly visible from all sections of the pool allowed rats to use a taxon strategy to locate the platform. The authors demonstrated that the beacon disrupted locale learning based on non-geometric cues. Using a smaller beacon, Hamilton, Rosenfelt, and Wishaw (2004) demonstrated that rats were able to use the two strategies sequentially. The rats used distal cues to initially head in the direction of the goal but switched to a taxon strategy when close to the visible platform. The results of Experiment 1 do not call into question the existence of the separate navigation strategies but do, along with previous experiments (e.g., Chamizo et al., 2003; Redhead et al., 1997; Hamilton et al., 2004), suggest that the nature of the interaction between the strategies may be different to the way in which O'Keefe and Nadel (1978) originally envisaged.

The results of Group Taxon in Experiment 1 illustrated that the presence of the visible platform did not disrupt learning about the relationship between the position of a platform and a non-geometric distal cue if the distal cue provided information on which to base a taxon strategy. This finding supports those of Jacobs et al. (1997) with humans and Gibson and Shettleworth's (2003) findings with rats. The results of Experiment 2, however, suggest that if the non-geometric distal cue required relational information to disambiguate it from other non-geometric cues then the visible platform would disrupt learning of a taxon strategy.

The information required to disambiguate the distal cue in Experiment 2 was relational, i.e., whether the red wall was to the right or left of the beige wall. There have been two suggestions as to how humans can encode such information. Hummel and Biederman (1992) suggested that the cues are represented by structural descriptions, which contain information about the spatial relationship between their parts. Thus the corner containing the correct platform may be represented by the structural description "red wall to the left of beige wall". Tarr and Bulthoff (1998) describe evidence for a different account of how relational information might be encoded. The participant could form a template, described as a "mental snapshot" (Cartwright & Collett, 1983), of the distal cues. The participant is assumed to compare the current view with the template in order to determine whether they are the same. The results of Experiment 2 do not discriminate between the two theories, as it could be possible that the presence of a visible platform disrupted forming either a complex visual template or a cognitive structural description.

The results from Experiment 3, in common with several animal experiments (e.g., Esber, McGregor, Good, Hayward, & Pearce, 2005; Hayward, McGregor, Good, & Pearce, 2003; McGregor et al., 2004; Pearce et al., 2001), demonstrated that learning to approach a visible beacon does not interfere with learning about geometric cues regardless of whether additional relational information is required to disambiguate them from other cues. This finding is much more in keeping with the O'Keefe and Nadel (1978) description of the formation of a cognitive map not being inhibited by the presence of proximal cues.

A very different view of spatial learning comes from the associative learning literature. Chamizo (2003) asserts that spatial learning follows the principles governing associative learning, suggesting that the findings of Chamizo et al. (2003) illustrated that the more salient visible platform overshadowed the less salient distal cues. In terms of the results of Experiment 1, the center of the red wall offers an equally salient cue to the position of the escape point from the pool as the view of the platform. It should therefore gain associative strength in the presence of the platform in the manner predicted by a competitive associative model such as the Rescorla-Wagner model (1972) and so not be overshadowed. When the platform was placed to the side of the red wall in Experiment 2, the distal cues associated with the correct platform contained elements in common with the distal cues associated with the incorrect platform. Both cues consist of the conjunction of a red and beige wall. As a result, the distal cues associated with the correct platform would lose associative strength and the visible platform would gain all of the associative strength, leading to poor spatial learning based on the distal cues.

Overall the results of Experiments 1 and 2 can be explained via associative principles. However, the results of Experiment 3, where the presence of a visible platform did not overshadow the shape cues, are more difficult for an associative analysis. A possible associative explanation would be that the corners of the isosceles shaped pool were more discriminable than the corners of the equilateral triangle used in Experiment 2. The more discriminable the corners the less likely they are to be overshadowed by the presence of the visible platform. Miles and Jenkins (1973) have demonstrated this effect of discriminability on overshadowing in instrumental conditioning.

If it were easier to discriminate between the corners of the isosceles pool compared to the corners of the equilateral pool, we would have expected that Group Shape Control would learn to identify the correct platform more quickly during acquisition and show a greater preference for the correct platform area in the test session than Group Relational Control. For these two groups the platforms were identical and participants had to use either non-geometric distal cues or shape cues, respectively, to locate the correct platform. Comparing the left panels of Figs. 6 and 9, there was no obvious difference in escape latencies between the groups. The number of times the participants made an incorrect choice of platform during training did differ greatly between the groups (Group Relational Control: $M = 5.25$, $SD = 3.36$; Group Shape Control: $M = 2.50$, $SD = 1.45$). Comparing the right panels of these figures, it can be seen that Group Shape Control travelled far more in the correct platform area than Group Relational Control. Although comparing across experiments is not ideal, the test result at least suggests that the corners are more discriminable for Group Shape than for Group Relational.

Reasons for a difference in discriminability have to remain speculative, but, if the participants in Experiment 3 have a representation of the pool that they are exploring as being an isosceles triangle, then it may have made the corner easier to encode as ‘the bottom right hand corner of an isosceles triangle’ than ‘the corner to right of the short wall’. Group Relational could only encode the position of the platform as being in ‘the corner to the right of the red wall’. Such an analysis of the difference between Group Shape and Group Relational fits better with the idea that relational evidence is encoded as a structural description (Hummel & Biederman, 1992) rather than as a ‘mental snapshot’ (Tarr & Bulthoff, 1998). One might consider that a structural description such as ‘the bottom right hand corner of an isosceles triangle’ was akin to using a locale strategy and a mental picture to be similar to a taxon strategy. The results would therefore suggest once more that a visible beacon does not disrupt locale learning with geometric cues. Such a suggestion that participants in Experiment 3 were using a representation of the whole isosceles triangle to encode the position of the platform supports previous work where people have been shown to use global cues (e.g., Wang & Spelke, 2000, 2002) but is at odds with recent animal studies.

Evidence that animals do not use the overall 'Euclidian' shape of an environment has come from two recent papers (Pearce et al., 2004; Tommasi & Polli, 2004) where the animals were able to use both local and global cues to locate a hidden goal. When tested in a new arena with a different shape, the animals searched in the area suggested by the local cues. In the Pearce et al. study, rats were trained to find a hidden platform in a rectangular watermaze and could use either the shape of the pool or the conjunction of a short wall to the left of a long wall to locate the platform. When tested in a kite shaped pool, the rats searched in the corner where the spatial arrangement of the walls was the same as in training. The authors concluded that if the rats were only using geometry to locate the platform they should have searched randomly in the kite shaped arena. The results suggested, however, that the rats were using the local cues to locate the platform.

In a reply to Pearce et al. (2004) and Tommasi and Polli (2004), Cheng and Gallistel (2005) conceded that the results precluded the notion that the animals were using the overall shape of the arena to locate the goal. However, the results could be explained if the animals were using a different shape parameter. Cheng and Gallistel suggested that the rats in the Pearce et al. (2004) study were using the principal axis through the rectangle and heading in a set direction from the end of the axis in order to locate the platform. Such a strategy would produce both the Pearce et al. (2004) and Tommasi and Polli (2004) findings. Cheng and Gallistel (2005) also stated that matching the principal axis between shapes was more parsimonious than matching the huge array of possible local cues such as angle of corner, color of wall, and spatial relationship between long and short walls. To test the hypothesis that the rats were using the principal axis over local cues, McGregor, Jones, Good, and Pearce (2006) trained rats to find a platform in an irregular pentagon and tested them in a rectangular arena. The rats searched in the corner of the rectangle that was consistent with them matching local cues rather than the principal axis of the two shapes.

Recent animal studies have also shown that learning about geometric cues can be influenced by properties of the walls creating the geometry of the environment. Such findings call into question the assertion by Gallistel (1990) that geometry is processed in a separate module and that the module is impenetrable to non-geometric features of the objects creating the shape. For example, Mackintosh (1975) found that the presence of a blue wall overshadowed learning about the geometry of a rectangular environment in relation to the position of a food source. Graham et al. (2006) found in a watermaze task with rats that the encoding of a kite shaped geometry was potentiated by the presence of different colored walls making up the pool. Finally, Pearce et al. (2006) found that learning about the geometry of a rectangular watermaze was blocked by pre-exposure to black and white wall cues in a square pool.

Review papers (Cheng, 2005; Cheng & Newcombe, 2005) have discussed various models for how non-geometric and geometric information might be encoded, ranging from being processed separately in modular systems, preferred by Wang and Spelke (2002), to being integrated within a unified system, supported by the recent animal data (Graham et al., 2006; Mackintosh, 1975; Pearce et al., 2006). The results of Experiment 3 are supportive of a modular processing of geometric cues. However, Cheng and Newcombe (2005) suggested that non-geometric cues which are used in isolation from the geometric cues, such as the visible platform used throughout the studies in this paper, might lead to modular processing. Geometric and non-geometric cues which are closely integrated, such as the colored walls in a rectangular arena used by Gray, Bloomfield, Ferrey, Spetch, and Sturdy (2005), produce integrated processing. Further studies varying the integration between non-geometric and geometric cues available to participants within the virtual watermaze would provide important information on how spatial cues are processed.

In conclusion, the results from Experiment 1 confirm previous findings from both animal and human studies that a visible platform disrupts locale learning with non-geometric distal cues. Experiment 2 demonstrated the novel finding that a visible platform can also disrupt taxon learning based on non-geometric cues requiring relational information to disambiguate it from other cues. Both sets of results can be explained by associative processes, though it is equally possible to explain the results via opposing navigational strategies. Results from Experiment 3 demonstrate that learning about geometric cues was unaffected by being trained to approach a visible platform, and these results are consistent with the suggestion that geometric shape cues cannot be disrupted by other spatial cues (Gallistel, 1990).

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