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Investigating Geometric Representation in Rodents

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Introduction

Many animals venture out from their home or nest in search of food. For example, a squirrel in search of food for the winter may journey far from their nest. Once they locate the food, the long journey back to their home begins. By being so far from their start point, the squirrel has become disoriented and must find a way through their environment in order to find their way back home. In order to accomplish this, animals rely on spatial representation while navigating. Spatial representation involves the relationship between surfaces and landmarks in one's environment. In order to utilize spatial representation in an animal's environment, the animal must encode the information about the spatial relationship between surfaces and landmarks with the goal (Cheng, 1986). In navigating in our own environments, we too utilize spatial representation to reach goals. We may remember that we put our keys down across the room from the television and next to the lamp. It is using these representations of where the goal is in relation to landmarks around us that we, and many animals, are able to successfully navigate in our surroundings.

The ability of animals to navigate successfully through their environment has led to researchers presenting a number of theories that explain how animals do this task. The animal and the type of environment that the animal is in influences the mechanism that the animal utilizes to get to their goal. One such mechanism is dead reckoning, in which the animal has an internal sense of the direction and distance to their goal from their current position. Foraging desert ants have been shown to utilize this mechanism. Another way that animals find their way back home is through the use of beacons, or proximal cues, and distal cues. These cues are landmarks that are either close to or distant from the goal, respectively. Animals store the knowledge of where the goal is in relation to these landmarks, thus making a spatial representation of their environment in order to find their way to the goal location (Shettleworth, 2010).

Another theory of how animals navigate through their environment is that of a geometric module, initially proposed by Cheng (1986). This module was generated based on the surprising failure of a spatial representation study. The study had rats in a rectangular enclosure, which had three identical black walls and one white wall. Unique panels were placed in each corner, and there were different smells from two of the corners. The rats were then placed into the enclosure, and the goal location was shown to them. This was done by having the goal be clearly visible to the rat. After finding the goal location, the rat was moved to an identical box that had a different orientation in the experimental room. Now the rats were faced with the task of finding the goal, which was now hidden in the same location. While searching for the hidden goal, the rats failed to narrow their search of the goal from two corners to one. The two goal areas that the rat was searching near were the correct location, and its geometric equivalent corner, which was rotated 180° from the goal corner. Despite the available visual and olfactory cues to the rat, which would have easily distinguished the correct corner, the rat still failed to narrow its search (Cheng, 1986). These results lead to the idea of an encapsulated geometric module (Cheng, Huttenlocher, & Newcombe, 2013). Cheng's 1986 study was not the only experiment to suggest a geometric module for spatial navigation. Benhamou and Poucet's 1998 study also suggested that rats utilized a geometric module. In their study, the rats were placed into a circular swimming pool which had distinct landmarks above the water. Two different paradigms were done to illustrate the use of geometry in their navigation. In the first experiment, the cues were arranged into an equilateral triangle, which did not give any useful geometry information to solve the task. When the cues were organized in this fashion, the rats performed at chance level at solving the task. When the cues were arranged in an isosceles triangle, however, the geometric configuration allowed for the rats to have available geometric information. In this experiment, the rats were able to successfully solve the task after the 75 training trials (Benhamou and Poucet, 1998). The results from this study also suggest the use of a geometric module in spatial navigation.

Rats are not the only animals that have been shown to use geometry for navigation. Birds, fish, as well as humans have also demonstrated this ability. Studies have found that young children, ages 18 to 24 months old, use geometry in an unmarked room to find a hidden goal. Similar to rats, the young children search mainly in the correct corner and in the rotationally equivalent corner (Hermer & Spelke, 1994; Learmonth, Newcombe, & Huttenlocher, 2001). The use of a geometric module has been extensively studied in a variety of species.

A number of explanatory frameworks which explain the geometry module first explained by Cheng have been proposed. One approach is the modularity model. In the modularity model, the geometry information available in the immediate environment is used to reorient an animal, while the featural cues are ignored. In terms of evolution, the modularity model is advantageous because the geometric cues are unlikely to change, while the featural cues of an environment can undergo drastic changes (such as the changing of colors and falling of leaves on a tree). The initial modularity model contains important information for navigation, including distance and direction. However, this initial model does not include angle or length information. This led to modified versions of the modularity theory which includes information about angles (Cheng, Huttenlocher, & Newcombe, 2013).

Another framework approach that has been proposed to explain the geometry module is the neutrally based two-factor computational theory. In this taxon system approach, it is believed that animals can learn both geometric and featural cues and that these cues are not separated but are both contained within edge-based views. Edge-based views are generated from the salient edges, which give different characteristics of the same view. This taxon system predicts the basic results seen with Cheng's 1986 study and also is consistent with information about grid cells, place cells and head direction. Based off of this theory, it is predicted that the rotational errors come from comparison of the different edge-based views (Cheng, Huttenlocher, & Newcombe, 2013).

This edge-based views approach led to this present study. Based on the assumptions of edge-based views, the current study explored how the addition of more salient edges to the testing arena would affect rotational errors in Cheng's working memory paradigm. The present study's goal was to replicate the study done initially by Cheng, and collect evidence supporting the idea that the rats' behaviors were not from use of the geometry module, but rather the use of additional salient edges. The hypothesis of this study is that rats who had additional salient edges in their testing environment will make fewer rotational errors while trying to locate their reward.

Methods

Subjects

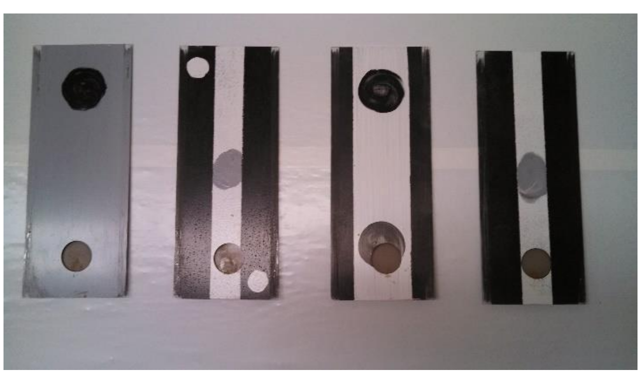
Sixteen male Sprague Dawley rats were used as subjects for this study. Data collection began in August 2013 and was completed in December 2013. All of the rats had prior exposure to similar spatial navigation tasks, but not to the specific paradigm at hand. The rats were on a water restricted schedule. They were given 30 minutes of free watering time during testing days and were free watered on weekends. The reward used was chocolate milk. Upon choosing the correct goal location, the rats were allowed 20 seconds of reinforcing reward.

Testing arena/Apparatus

The experiment was conducted in two separate arenas. Both apparatuses were 122 cm x 61 cm x 38 cm, with an opened top. The boxes were identical to one another. There were three black walls, and the fourth wall was one of the long walls. For one group of animals, the fourth wall was completely white (white group). The other group had the fourth wall as a white wall with a black stripe (39 cm wide) down the center of the wall (striped group). All of the walls of the box were removable. The fourth wall was switched between the white and striped group trials. The floors of both the exposure and test box were white. In the four corners of each testing arena, there were panels set at 45° angle to the corner. Each corner panel had a different design. One panel was gray with a black dot at the top of the panel. Another panel was black with a white stripe down the center. This panel had a gray dot in the center and two white dots on opposing top and bottom corners. The third panel was again black with a white stripe down the center, and only had a gray dot in the center. The final panel was white with two black stripes down the sides. This panel had two black dots on the top and bottom of the middle of the panel (see figure 1). In the panels of the test box, circular doors were cut out 4.5 cm from the base of the panel. These door holes were 4 cm in diameter and had Lexan doors/flaps which were shaded to prevent the rats from looking through the doors to use visual cues to determine the location of the goal reward. In the exposure box, there were identical panels except for the doors. The panels were painted with the same designs, however, they were painted to appear as though they had a door. The panels were actually solid and had no door access. The chocolate milk was placed in the reward corner in a plastic dish (2.5 cm diameter). The dish was raised to nose level for the rats to facilitate access to the reward. In the non-reward corners, there were 10 mL beakers which contained chocolate milk, but were inaccessible to the rats. The placement of inaccessible chocolate milk was used to eliminate any odor cues that the rats might have been using to help navigate to the correct goal corner. Suspended above both the exposure and test box was a light and camera. The light was 109 cm from the top of the testing arena. A LYD CM208CA mini camera was also over both boxes and was 130 cm from the top of the boxes. The camera feed was sent through to the tracking program, EthoVision XT 8.5 where the activity of the rats was recorded.

Figure 1A: Testing apparatus for the striped wall group

Figure 1B: Distinct corner panels



Training

The training was conducted to accumulate rats to the testing area. Initially, the rats were placed in the box in order to explore the apparatus and become familiar with the panels and doors. The doors were opened fully to encourage nose poking behavior. Each rat was left in the apparatus for 3 minute segments to adjust to the testing environment. Over the course of a week, with each rat getting one trial/exposure per day, the doors were systematically lowered each day. During this exposure period, there was chocolate milk in each corner to encourage drinking and to learn that to access the reward, the animals would have to poke their head through the doors. Once the rats had mastered the head poking behavior, the training of the actual protocol began. Rats were placed in the first box, the exposure box. In the exposure box, the goal location was the only panel which had the door. The door was fully opened. This showed the rats which of the possible four goal locations was the correct choice for the given trial. The other three panels appeared as though they also had doors, but they did not. This eliminated the possibility of the rats attempting to open incorrect choices. Once the rats had poked their head through the correct and opened door, they were given 20 seconds to drink the reward of chocolate milk. After that time had elapsed, the rat was removed from the exposure box and placed back into their cages for a delay period of 75 ±5 seconds. For 20 seconds of that delay period, the rats were slowly turned counterclockwise, to disorient the rats and to discourage the use of room cues in navigation. After the delay period had passed, rats were placed into the testing box. The test box was identical to the exposure box, except for the panels. In the test box, all panels had actual doors and all were closed. This hid which panel was concealing the reward, thus forcing the rats to use their spatial and geometric knowledge of the box to navigate to the goal corner. The rats were placed into the box according to their randomized start location. Once the rat had chosen the correct goal location, it had 20 seconds of reinforcement to drink the chocolate milk. After that time, the rats were removed from test box and were returned to their cage. If the rats had not chosen a corner (choosing a corner was determined to be if the rat poked their head through the door, simply sniffing the area was not considered a decision/head poke) after two minutes of being in the test box, they were placed in front of the correct corner.

Testing

The boxes location within the testing room was randomized every day, resulting with a new box location for each trial. The panels were also randomized for each rat for every new trial. The orientation of the panels was identical from the exposure to the test box. The goal locations were randomized for each trial and were consistent from the exposure box to the test box. Starting locations were also randomized for each rat. The starting locations were different from the exposure box to the test box. This was done to inhibit rats from simply memorizing the movements required to find the goal location. Rather, it encouraged rats to use their knowledge of their spatial surroundings.

The testing method was identical to the training method. In the testing phase, the decisions made by each rat in both the exposure and test box were recorded. Upon observing the results, the protocol was adjusted slightly to create a second experiment to investigate the influence of odor cues on the rats' behaviors.

The second experiment was similar to the protocol for the first experiment. In the odor control experiment, there was chocolate milk behind every door in the test box. However, the rats could only access the milk that was in the correct goal location. The other three corners had beakers with the chocolate milk to eliminate the use of odor cues in finding the correct location.

Results

The rats learned to solve the task after a few weeks of training with the paradigm. The rats' performance was variable; the pattern of behavior selections was not the same for all rats as time progressed. However, each rat did have performance levels above chance.

Experiment 1

The first experiment examined the effects of additional salient edges on performance. During this experiment rats in both groups were performing above chance level. Both groups showed similar results. 54% of choices made by the striped group were for the goal corner. 14% of the choices were for the rotational equivalent corner. Together, 68% of the choices made by the striped wall group were for one of the correct corners. 31% of the choices were the two other corners, noted as the error corners. See figure 2.

The white wall group showed very similar results. Again, 54% of the choices made by the white wall group were for the goal corner. The rotational equivalent corner made up 16% of the choices. Together, this meant that 70% of the choices were for one of the correct corners. This left 29% of the choices to the error corners. See figure 3. Both the striped and white wall group showed corner selections between the correct and incorrect choices that were significantly different.

Experiment 2

The second experiment eliminated odor cues to explore how they were impacting the rats' behavior. When odors were controlled for, both groups' performances dropped to near chance levels. For the striped wall group, rats were choosing the goal corner for 15% of the choices and the rotational equivalent corner for 32%. Therefore, 47% of the choices were for one of the correct corners. 52% of the choices were for the incorrect corners. See figure 4.

The white wall group also showed behaviors close to chance. The rats were choosing the goal corner 22% of the time and the rotational equivalent corner for 30% of the choices. This meant that 52% of the choices were for the one of the correct corners. The rats were choosing the incorrect corner for 47% of the overall choices. See figure 5. Both the striped wall and the white wall group did not have significantly different corner selections between the correct and incorrect locations.

Figure 2: Experiment 1—Striped Wall Group

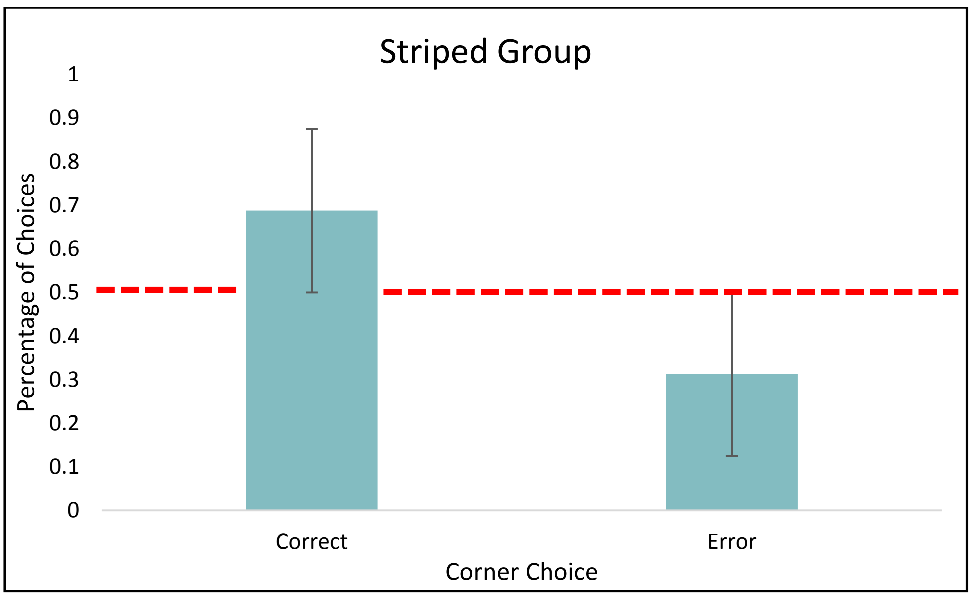


Figure 3: Experiment 1—White Wall Group

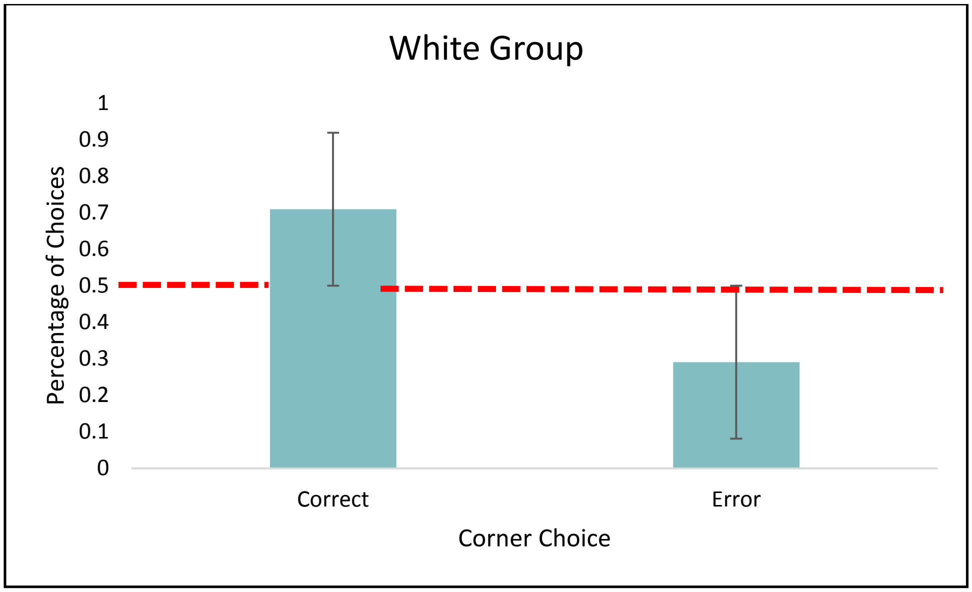


Figure 4: Experiment 2—Striped Wall Group

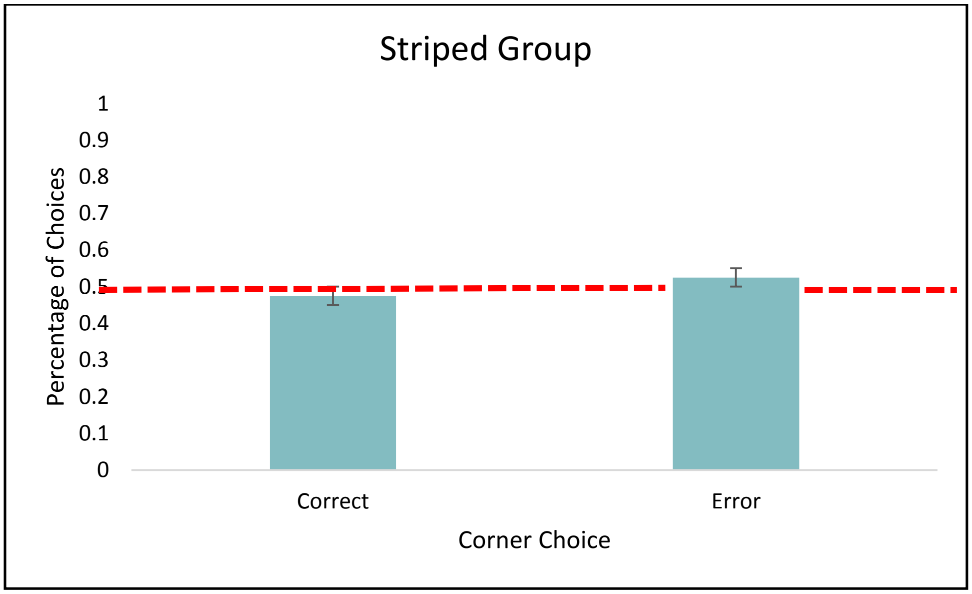
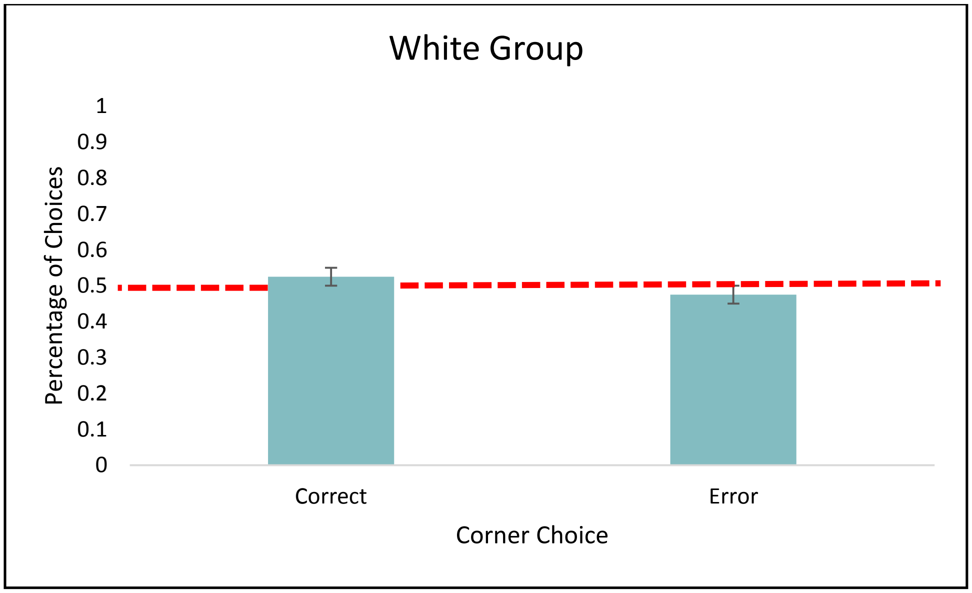


Figure 5: Experiment 2—White Wall Group



Discussion

The rats' behaviors are similar to those observed in Cheng's 1986 study. The rats were selecting either the goal or the rotational equivalent location above chance. Based on the results from the first experiment, the rats were exhibiting behaviors similar to those seen in Cheng's study because the rats were unable to narrow down their selection between the goal location and the rotational equivalent location successfully.

This study hypothesized that the addition of more salient edges to the exposure and testing arena would increase rats' performance. However, this effect was not observed. There was no significant difference in performance between the two groups. These results suggest that the rats' successful navigation is not dependent on salient edges, and thus does not support the edge-based views hypothesis. There may have been a number of additional factors influencing the rats' behaviors. The animals could have been utilizing the geometric representations within the arenas or they could have been using other cues. As the study was progressing, it was observed that both groups were performing similarly. This prompted the researchers to adjust the protocol and include a second experiment. This experiment controlled for odor and was done to examine if the rats were using odor cues from the reward, chocolate milk, to help them navigate to the correct goal location. This was accomplished by having chocolate milk in every corner of the test box, while the rats could only access the chocolate milk in the correct location.

During the second experiment that controlled for odor, both groups' performances dropped to chance levels. The rats were selecting the incorrect corners almost as frequently as they were selecting the correct corners. These results suggest that the rats were using odor cues for some aspect of their navigation to the goal. However, correct choices were not entirely eliminated when odor was controlled for. This suggests that rats were not solely relying on the odor of the goal to successfully navigate. The other techniques or methods that the rats were utilizing are unknown from the results of the current study.

Odor cues can greatly influence the results of an experiment, as seen in the present study. While in this study we attempted to control odor cues by creating odors for every possible choice, there are other ways to do this. One potential method for controlling odor cues would be to use a reward that does not have quite as strong of a scent, such as sucrose pellets or water. By using a reward that has minimal odor, the rats will be unable to use that type of cue when trying to successfully navigate for a given task. Controlling for odor cues is important because when animals use these types of cues, their navigation is not based on the navigation method being tested, but rather due to a different variable. By making these slight adjustments in future studies, the results will be more telling about how rats navigate and the results will not be skewed through the use of odor cues.

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