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A Comparison of the Associative and Multiple Bearing Hypotheses through Landmark Stability in Humans Using a Virtual Environment

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A COMPARISON OF THE ASSOCIATIVE AND MULTIPLE BEARINGS HYPOTHESES THROUGH LANDMARK STABILITY IN HUMANS USING A VIRTUAL ENVIRONMENT

by

MARTHA R. FORLOINES, B.S.

Under the Direction of Kent D. Bodily

ABSTRACT

The current experiment investigated the mixed results seen in spatial blocking paradigms; there have been procedures that have shown and not shown blocking of added landmarks in the spatial domain. Typically, the Associative theory of learning has been applied to spatial learning. However, spatial blocking paradigms cannot be explained solely with this theory. The Multiple Bearings Hypothesis (MBH) may be able to explain these differences. The current experiment employed a three-phase blocking paradigm to examine what factors are responsible for the mixed results. The first Phase, Phase 0, incrementally shaped human participants' goal location behavior with two ambiguous landmarks. In the second phase, Phase 1, participants experienced one additional landmark that disambiguated the location of the goal. The third phase, Phase 2, presented three additional landmarks. Participants were divided into three groups that experienced stability of the landmark presentations in Phase 2 differently. Results showed that the MBH can help to explain the results with spatial blocking. Participants were able to locate the goal in the presence of the added landmarks. Participants learned about the added landmarks as they relate to the goal location. However, landmark stability and proximity are important factors that affect subsequent learning of added landmarks.

INDEX WORDS: Spatial Blocking, Associative Theory, Multiple Bearings Hypothesis, Landmark Learning.

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DEDICATION

This thesis is dedicated to Tannie for holding my hand through the process, and my family for pushing me to find what I love.

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I would like to thank Bradley R. Sturz for inviting me to participate in his lab at AASU. Without that, I cannot imagine where I would be today. Also, Kent D. Bodily for helping me formulate this thesis and always taking the time to make sense of it all. Finally, I would like to thank Janice Steirn for helping me appreciate the little things; a little R+ never hurt anyone.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

There have been varied results with spatial blocking paradigms. The current experiment investigated the differences and similarities between the Associative theory and the Multiple Bearings Hypothesis (MBH). Further, the differences between these theories could help to explain why researchers are getting such varied results. Human participants experienced a blocking paradigm in which a three-landmark array was presented that signified the location of the goal. After asymptote was reached with the three-landmark array, three additional landmarks were presented along with the initial array in the second phase of the paradigm. Human participants were divided into three groups in which the stability of the added landmarks was varied across trials based on bearing and distance to the goal location to test the assumptions of the MBH. If participants were able to locate the goal throughout testing, then the MBH may help to understand what participants are learning about the added landmarks.

How This Study is Original

This research is original in that the differences between groups will allow for a comparison of the two theories. The groups will differ in presentation of the Phase 2 landmarks, which will vary trial-by-trial in either distance to the goal or bearing toward the goal. This difference will allow for an idea of what properties participants are learning about each landmark. Further, results will be able to determine if the Associative account or the MBH can account for mixed results in various spatial blocking paradigms.

CHAPTER 2

A COMPARISON OF THE ASSOCIATIVE AND MULTIPLE BEARINGS HYPOTHESES THROUGH LANDMARK STABILITY IN HUMANS USING A VIRTUAL ENVIRONMENT

Spatial Learning

Spatial learning is defined as learning about the spatial relationships among stimuli in ones' environment. At a most basic level, it is the ability to navigate consistently from one location (e.g., home) to another known location (e.g., food, safety, etc.). At a more complex level, animals learn the relations among the locations of stimuli and are able to navigate reliably and directly among locations. There are multiple mechanisms by which animals navigate from one location to another. Some animals use self-generated cues to navigate (Leising & Blaisdell, 2009). For instance, some insects leave a scent trail as they navigate away from the home. This method allows them to successfully navigate back to the home via odor cues. Another method of spatial navigation is image matching, in which an animal takes a snapshot of the environment as it is leaving the home. On its return, the animal compares its current view to the stored image to determine its position in the environment. One component of spatial navigation is path integration. This is the process in which an animal continually integrates self-generated motion cues (e.g., vestibular, kinesthetic, optic flow cues) to update its perception of the direction and distance to the home, allowing it to return directly to the home in the absence of learned landmarks. These mechanisms allow animals to effectively navigate away from and return to a home site, but are limited with regard to directly navigating among multiple locations (Biegler, 2006).

Landmark Learning

Animals can use specific features of the environment to guide and concentrate their search when navigating to a goal. This type of learning, landmark learning, is defined as learning about relationships among objects in the environment. An animal may learn landmark–to-goal or landmark-to-landmark spatial relationships. Evolutionarily, the ability to navigate one's environment via landmarks is advantageous; the ability to store and recall the location of a variety of food sources allows for survival even if one cache is lost to the elements or predation (Kamil & Cheng, 2001).

Landmark learning has been studied in a variety of animals including bees, birds, rats, monkeys, and humans (for a review see Brown, 2006; Kelly & Gibson, 2007). Research has shown that animals are able to use environmental items as landmarks while searching. In a review of landmark learning, Leising and Blaisdell (2009) point out that animals are able to locate a goal based on landmarks in the environment. Animals can use room cues as landmarks to locate a goal in an otherwise barren environment. Animals are also able to learn the relationships of multiple landmarks to a goal.

Associative Account

Rescorla and Wagner (1972) developed a model of associative learning which states that a stimulus gains associative strength based on the contiguity and contingency to the reinforcer. As stimuli are paired in time or space, the predictability of the stimulus to the reinforcer is strengthened; as such the associative strength is increased. If there is more than one stimulus, then the predictive value of each stimulus to the reinforcer must be divided among the stimuli, thus each stimulus will have a lower portion of associative strength. Further, the model suggests that there are phenomena that inhibit learning. One phenomenon, overshadowing, can occur when two stimuli, presented simultaneously, are paired with a reinforcer. If the stimuli differ in saliency, the less salient stimulus gains less associative strength than the more salient stimulus. When testing each stimulus alone, tests will show that less learning has occurred with the less salient stimulus than with the more salient stimulus. Another phenomenon, blocking, can occur with the addition of a new stimulus of the same saliency of a pre-trained stimulus-reinforcer association. The predictability of the initial stimulus to signify the reinforcer will be strong enough that no learning will occur with the added stimulus. The model suggests that there is only a certain amount of associative strength available to the relationship. The addition of a second stimulus after learning has occurred will not allow for any more strength to be assigned to that stimulus due to the initial stimulus already reliably predicting the reinforcer (Rescorla & Wagner, 1972).

The Rescorla-Wagner model of associative conditioning can be applied to landmark learning. As a landmark (stimulus) is paired with a goal location (reinforcer), the landmark-to-goal relationship gains associative strength. As the number of landmarks in the array increases, each item shares associative strength as a compound stimulus that is predictive of the goal location. The extent to which a landmark is predictive of a goal location depends on its proximity (contiguity) and stability (contingency) to the goal location. If two landmarks are equally predictive of the goal, each will have gained an equal amount of the associative strength. However, if two landmarks are presented simultaneously, but one is distant or unstable and another is proximal and consistently predictive of the goal, overshadowing of the less predictive stimulus can occur. Further, once asymptote has been reached with an initial landmark array, added landmarks to the array with similar stability and proximity in relation to the goal as the initial array will be blocked (Biegler & Morris, 1999).

Evidence Supporting the Associative Account

Spatial blocking occurs when the available associative strength has to be divided between stimuli such as landmarks and the surface geometry (shape) of the enclosure (Cheng, 2009).

Chamizo, Manteiga, Rodrigo, and Mackintosh (2006) examined the associative theory of spatial learning by testing whether overshadowing occurs in the spatial domain. Rats learned to find a hidden platform in a Morris Water Maze (for a review of the Morris Water Maze, see Leising & Blaisdell, 2009) with the use of landmarks located on the outside edge of the pool. The researchers varied the distance of the landmarks from the platform, such that one landmark was close in proximity to the platform and another landmark was distant from the platform. The researchers found that the distance of the landmark to the platform had a significant effect on the rats' ability to consistently find the goal when the distal (distant from the platform) and proximal (close to the platform) landmarks were tested alone. The proximal landmark allowed for the most precise search when tested alone, suggesting that the proximal landmark gained more associative strength than the distal landmark. The proximal landmark overshadowed learning of the distal landmarks.

Timberlake, Sinning, and Leffel (2007), assessed spatial blocking in a Morris Water Maze task with rats. The researchers used proximal and distal landmarks to signal the goal location across multiple experiments. The landmarks were either intra-pool landmarks or distal background landmarks that were either varied or fixed across experiments. In Stage 1, landmarks were either proximal or distal, and stable or unstable. The researchers then added landmarks during Stage 2 training once asymptote was reached with initial landmarks. For instance, in one experiment the initial training was with a fixed or varied proximal hanging landmark that shifted in the pool along with the goal location; varying the relationship to fixed environmental landmarks (room cues) and the goal. In Stage 2, the researchers added four fixed background landmarks, and tested with varied presentations of the landmark arrays. The following experiments were similar, but varied the Stage 1 and Stage 2 landmark-to-goal presentations.

Overall, they found that the proximity and stability of the landmark to the goal location affected subsequent learning. If the pre-trained landmark was fixed and consistently predictive of the platform, as well as being proximal to the goal, then blocking would occur with added distal landmarks. However, if the pre-trained landmark was varied or distal to the platform, the added proximal landmarks would be learned. These results support an associative account of spatial learning, suggesting that proximity and stability are important assumptions of the model.

Biegler and Morris (1996) also investigated the importance of landmark stability in a set of experiments with rats in a square enclosure. The rats were trained with fixed or variable positioned landmarks in relation to the distance from the goal. The results indicated that there was a decrement in the rat’s ability to find the goal location when the landmarks did not maintain a stable relationship to the goal location. This supports the associative account that the landmarks must hold a consistent relationship (contingency) to the goal to be learned. The variable landmarks were unable to gain sufficient associative strength, and therefore were unable to control search during testing.

Alexander, Wilson, and Wilson (2007) found mixed results when testing blocking based with uniquely-shaped landmarks in a virtual environment. Human participants were instructed to find a goal location based on the presentation of landmarks. Through five experiments, the authors investigated what factors could affect spatial blocking with landmark arrays (multiple landmarks positioned in the environment as a compound stimulus). Specifically, they found that when only one landmark was pre-trained, blocking did not occur. Further, they found that when adding a distractor task between trials to prevent rehearsing of the landmark-to-goal relationship, blocking did not occur. However, when the previously trained landmark was presented with multiple, less salient landmarks during phase 2, blocking occurred. The authors contend that blocking occurs, but not across all situations. Specifically, these results indicate that added landmarks can be blocked by pre-trained landmarks.

Evidence against the Associative Account

The previous results support the associative account of spatial learning by explaining the decrement in landmark learning when multiple landmarks are presented during training and then tested alone. However, the associative account appears to be unable to account for other empirical results (Hayward, McGregor, Good, & Pearce, 2003; Hardt, Hupbach, & Nadel, 2009). In the experiment described by Alexander, Wilson, and Wilson (2007), described above, when one landmark was added to one pre-trained landmark, blocking did not occur. This suggests that in a barren environment, subsequent learning of an added landmark will occur, even when asymptote has been reached with a pre-trained landmark. This is in direct conflict with the associative theory, suggesting that added landmarks can be learned.

Further, Biegler and Morris (1999) trained rats to find food with arrays of landmarks. First, rats were trained to find hidden food between two identical landmarks. The hidden food was equidistant from the two landmarks, but was to one side of the landmark-landmark vector (the spatial relationship between two landmarks). Since the landmarks were identical, they were ambiguous regarding the side on which the food was hidden. After the rats learned to search on both sides, the researchers added a third, visually different, landmark (LMa) to one side of the ambiguous array, which disambiguated the location of the food. Once the rats were able to find the food consistently with this three-landmark array, another, visually different, landmark (LMb) was added to the array on the opposite side of the ambiguous landmarks than LMa. LMa and LMb were equally close to the goal location, but differed in their distance to the ambiguous landmarks. After a fixed number of trials, rats were tested on LMa and LMb in various landmark array presentations. For instance, the interchanged test consisted of LMa and LMb in switched positions in relation to the training position; such that LMa was in LMb’s training position and vice versa. This test was to determine if spatial blocking would occur. If the rats were able to locate the goal while the landmarks were interchanged, then blocking would not have occurred. Results showed that LMb did not gain control over the rats searching behavior when tested. Specifically, during the interchanged test, search was focused in the goal location. The authors concluded that the obtained result was evidence of blocking in the spatial domain. However, the rats correctly responded during the interchanged tests to the array of the landmarks, suggesting that learning did occur with the added landmark. This seems to be, at best, an incomplete example of spatial blocking. The rats learned about the LMb location in relation to the array, but not the landmark identity as it was different in appearance than LMa. An alternative explanation of the results could be that the positional information (how the array was positioned) about the added landmark was learned and was more salient than the identities of the landmark (Biegler, & Morris, 1999).

Hayward et al. (2003) found that overshadowing and blocking did not occur in a Morris Water Maze when rats were trained with proximal landmarks and geometric room landmarks. In particular, the pool was enclosed by a rectangular shape, allowing the rat to search at one corner of the enclosure for the platform. Through multiple experimental variations, the presentation of a salient landmark during training or after asymptote had been reached would assess the phenomena of overshadowing or blocking respectively. However, rats were able to find the goal when the landmarks were removed during testing with only the rectangular room geometry to locate the goal. Further, the rats were able to locate the goal when only the landmarks were available without the room geometry present. This suggests that blocking in the spatial domain does not occur when all landmarks are as salient as the pre-trained landmarks, and that the salience of the landmarks available to the animal may be the reason for the decrement in performance as seen by other researchers.

Multiple Bearings Account

The associative theory states that there is only so much that can be learned about an environment to locate the goal. Once that information is learned, the addition of landmarks to the environment does not increase the likelihood of finding a goal, and will not be learned as well, or at all. This does not appear to be the case, especially with animals that cache many stores of food. Kamil and Cheng (2001) point out that birds are incredibly precise when locating a cache of food; even when the environment has drastically changed (i.e., snow cover), or when the additional landmarks are distant from the food cache. An alternate extension of the associative theory is the multiple bearings hypothesis (MBH).

Kamil and Cheng (2001) proposed reasons why some errors do not occur during search with caching animals. In the MBH, there are two critical pieces of information provided by individual landmarks: bearing (or cardinal direction from the landmark to the goal) and distance from the landmark to the goal. Search is concentrated along the intersection of the landmarks based on each of the estimates provided by the landmark. Search errors are seen in what Kamil and Cheng (2001) call the “zone of uncertainty” (p. 107). This area is defined by the polygon created by the intersection of landmark-to-goal vectors (see Figure 1 for examples). According to this hypothesis, the zone of uncertainty will decrease as the animal is provided with more information about the exact location of the goal. Animals may make errors because the intersection estimate is not precise (Sturz & Katz, 2009). Landmarks added to the environment, provided they add a unique bearing to the goal, allow for a more restricted search around the goal location. As long as the contiguity (proximity) and contingency (stability) to the goal from the landmark are stable and unique, then they will be learned. However, if the added landmarks do not add a unique bearing to the array, then they will be blocked. For instance if a pre-trained landmark-to-goal bearing is north, and an added landmark-to-goal bearing also is north, then the second landmark does not add a unique bearing, thus will not be learned (Kamil & Cheng, 2001).

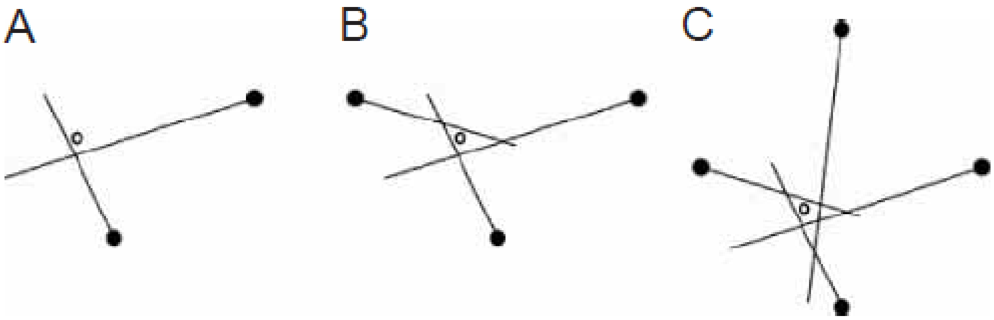

Figure 1. Landmarks are filled black circles, the goal location is the open circle, and solid lines are landmark-to-goal bearings. A. shows bearing estimates with 2 landmarks. B. shows bearing estimates with 3 landmarks. The polygon created around the goal location allows for search errors. C. shows bearing estimates with 4 landmarks. The polygon created around the goal location allows for greater accuracy when searching than with 3 or 2 landmarks. Copied from Kamil & Cheng, 2001, p.108.

Evidence Supporting the MBH

Biegler, McGregor, and Healy (1999) examined different strategies that could be implemented by birds when searching for food with two landmarks. They found that searching in the center of the two-landmark array with novel distances between landmarks than presented during training seems to be the most effective strategy, and occurs when the landmarks are in the same alignment (north and south). Birds search in the midpoint between landmarks, though they show error based on the distance vectors. If the landmarks are close to each other, then the search area is concentrated, however, the further the landmarks are to each other, the more error during search. Kamil and Cheng (1999) show that distance estimates are less reliable than bearing estimates. Specifically, the further the distance, the harder it is to estimate. However, the bearing estimate is only based on one piece of information. Distance is based on a start and an end point between two landmarks or from one landmark. The animal must recall where to start, and how far to travel from the start point. This is a two-part process, whereas bearing estimates are a one-part process; the animal must travel in one direction.

Sturz and Katz (2009) trained pigeons to find a goal based on the distance and direction varied by experiment. When tested with a varied training landmark (i.e., features of the landmarks changed), pigeons were able to estimate goal position based on distance and bearing. The authors point out that distance errors were greater than bearing errors. This supports the assumption that distances are harder to estimate than bearings.

In relation to the failures to find spatial blocking, the animal could learn about all landmarks presented and allow for a multitude of information (distance and bearing) in order to allow for greater search accuracy. Specifically, in Sturz and Katz (2009), when the pigeons were presented with only one landmark, they searched in the correct area based on only one landmark’s distance and directional information. Further, when the landmark array was rotated with orienting cues on the landmarks, the pigeons search behavior was within the zone of uncertainty. These results suggest that the pigeons were learning the distance and direction from each landmark in relation to the goal location.

CHAPTER 3

Current Research

The current study employed a dynamic three-dimensional virtual environment as the apparatus. In humans, spatial learning can be assessed by using real or virtual environments. This has allowed for a greater understanding of animal models and how they translate into human processes of learning about environments (Kelly & Gibson, 2007). In a review of spatial learning in humans across real and virtual environments, Kelly and Gibson (2007) pointed out that the ability to utilize virtual environments has expanded the ability to learn about human spatial learning. The review contends that virtual environment experiments are more economical and allow for a larger sample size than the use of real world analogs of the same task. These tasks have ranged from a virtual radial arm maze to a virtual enclosure task analogous to those used in nonhuman animal studies. The virtual environment studies have allowed for similarities and differences across species to be studied (Kelly & Gibson, 2007).

Further, Sturz, Bodily, Katz and Kelly (2009) validated the use of virtual environments as similar to real-world environments as showed that this apparatus is a good method to assess spatial learning. The researchers replicated a virtual environment experiment by Sturz, Bodily, and Katz (2006), to determine if the use of real and virtual environments is comparable. Results showed similar performance between participants in the real and virtual presentations. Though there are limitations to using a virtual environment (i.e., lack of physical movement by the participant, vestibular cues, etc.) the similar results shown in direct the direct comparison across real and virtual environments contends that the use of virtual environments is valid for use in this type of research (Sturz, et al., 2009).

The purpose of the current experiment was to determine what factors are responsible for the varied results within previous spatial blocking experiments. Participants were trained with an ambiguous two-landmark array, in which the goal is located to either side of the array. Next, participants were presented with a disambiguating landmark to allow for a precise search to one side of the array. Finally, participants were divided into three groups in which the stability of three added landmarks was manipulated. The groups were presented with the initial training array as well as three added landmarks that were either stable landmarks, landmarks that provide a stable bearing to the goal, or landmarks that provide a stable distance to the goal.

The manipulation of landmark stability and use of a blocking paradigm can be a valid method to studying spatial learning. If the landmark-to-goal relationship must be stable in order to be learned, then the presentation of a stable and an unstable landmark would be a good test to examine spatial blocking. The current study attempts to determine if the MBH can explain the differences in performance when landmarks are tested in various presentations. Previous research with spatial blocking has shown evidence for and against the phenomenon. Landmark stability and placement relative to the initial training array may be able to account for the differences in search performance. If participants' search behavior is not restricted around the goal location when added landmarks are stable without the presence of pre-trained landmarks, the associative theory will have gained support for its explanation of spatial learning. However, if added landmarks can be used to locate a goal after asymptote has been reached with a pre-trained landmark array, then the MBH may be used to explain spatial learning, suggesting that additional landmarks will focus search based on additional bearing and distance information added. Further, if the added landmarks are able to control search, then will the requirement of the MBH for landmarks to have a unique bearing to the goal effect search?

Chapter 4

Methods

Participants

36 undergraduates (20 male and 16 female) participated in this study. The participants were recruited from Psychology courses and awarded with either class credit or extra credit for their participation.

Apparatus

The interactive 3D virtual environment was created on the Valve Hammer Editor and run on the Half-Life Team Fortress Classic platform. A personal computer with a triple display flat screen monitor (2400 x 600 pixels, with a field of view of 115°) and speakers served as the interface for the virtual environment. Participants experienced the virtual environment in first-person perspective. A Logitech Dual Action gamepad was used to navigate and make a selection in the virtual environment. The left joystick allowed for navigation (forward, backward, left, and right). Any button on the right side of the gamepad (1-4) could be pressed to make a selection. The data was collected and recorded with Half-Life Dedicated Server on a similar computer in the experimental room.

Stimuli

All landmarks are identical in height, 76 vu and vary in width from 15 vu to 36 vu (see Figure 2). Two landmarks 0 (L0) is white and has two red stripes; one stripe was located horizontally around the cylinder in the midsection, and the second was located equidistant from the first stripe to the top of the cylinder. Landmark 1 (L1) is an hourglass shape with a blue base and top with a dark gray cylinder in the midsection; each portion of the landmark is the same height. Landmark 2 (L2) has a black thin cylinder with a red sphere atop. Around the bottom half of L2 are 5 red circular terraces surrounding the black base. Landmark 3 (L3) is a green and black pixilated pyramid with a pair of square terraces at the top portion of the pyramid. In the middle of the terraces is a black filling. Landmark 4 (L4) has a black thin cylindrical base with a yellow and black pixilated sphere on the top (see Figure 2 for landmark layout). The experimental room (1424 vu x 1424 vu with 712 vu radius) is round and consists of solid gray walls with a green grass floor, and a black ceiling.

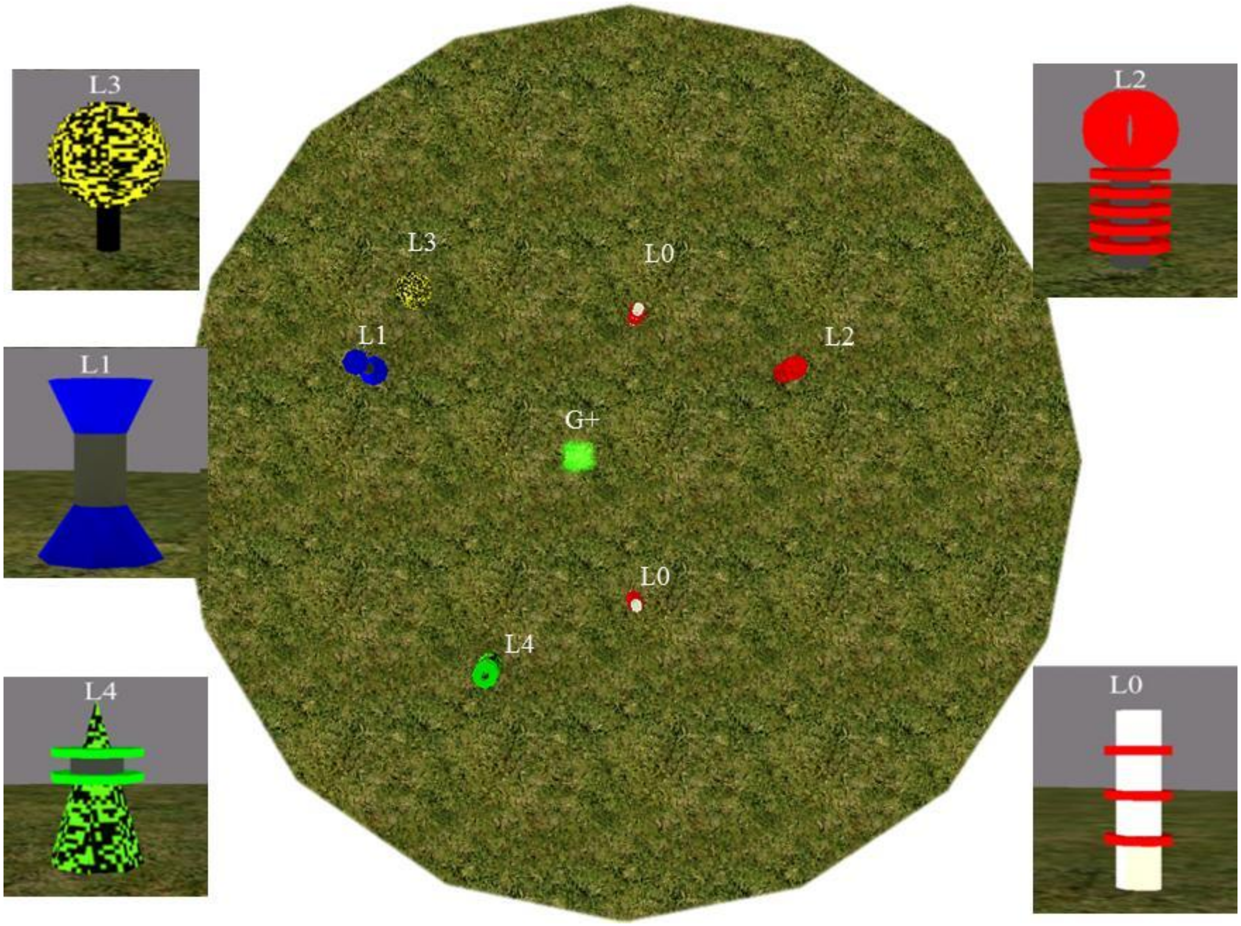

Figure 2. Birds-eye view of landmark placement and landmark identities. Landmarks are placed in the starting position for all groups and labels are added to identify individual landmarks.

Procedure

Participants were randomly assigned to one of three groups (Control, Stable Distance, and Stable Bearing). The experiment consisted of 43 trials with 7 test trials interspersed. There were three phases of training. Participants began each trial in one of four locations at the edge of the room facing toward the wall. A low tone played to signify the trial has begun. Participants were instructed to find the goal location (G+) which is 128 vu x 128 vu with a radius of 64 vu.

Phase 0. Trials 1 through 5 consisted of a two-landmark array. Two L0 landmarks served as ambiguous landmarks; such that the location of the goal could be located between and to one side of the two L0's, but which side (east or west) will be ambiguous. The L0 landmarks were positioned at 22.5° and 157.5° from north, and 236 vu from the goal location. These landmarks were stable, but do not allow for participants to determine on which side the goal is located. These trials are intended to introduce the participant to the task.

The participant's search for the goal was incrementally shaped over the course of the 5 trials of Phase 0. As the trials progress, the goal marker (a semi-transparent green sphere) became available when the participant approaches closer to the G+ area. On the first trial, the goal marker appeared when the participant approaches the L0 landmarks. The participant then navigated to the marker and pressed one of the gamepad buttons. Pressing the button completed the trial, and started a 5s inter-trial interval (ITI) during which the screen is black. On trial 2, the marker appeared when the participant breaches the circumference of a circle that passes through both L0 landmarks and is centered on the G+ location. The diameter of this activation area decreased through trials 3-5, with the participant having to dwell in the G+ location for 1s on trial 5.

Phase 1. Trials 6 through 15 consisted of the two L0 landmarks with the addition of a disambiguating landmark L1. L1 was positioned to the west of the two L0 landmarks at 292.5° from north, and was positioned 354 vu from the goal location. The three landmark array created a triangle shape that allowed for rapid goal location by disambiguating on which side of the L0s the goal is to be found.

The goal location can be found by navigating to the spot where the goal marker will appear. If the participant dwells in the correct spot for 3s, a green marker that will is paired with a "ding" sound will appear signifying they are in the correct location. The marker appeared if the participant fails to find the location after 45 seconds have passed in order to allow participants to finish the experiment in the time allotted. Once the goal location is found and the green marker has been presented, the participant can navigate to the goal and press any of the gamepad buttons to begin the ITI, and start the next trial. Each trial begins with a low tone to signify to the participant the trial has started.

Phase 2. Trial 16 through 49 consisted of the same L0 – L1 arrangement as Phase 1. All groups experienced 3 additional landmarks L2, L3, and L4. L2 was at 67.5˚ from north and at 354 vu from the goal location. L3 was at 315˚ from north and at 354 vu. L4 was at 202.5˚ from north and at 354 vu from the goal location. For the Control group, these landmarks were stable in their location. The difference between the Control and experimental groups was the stability of the added landmarks L3, and L4. L2 was stable for all groups. For the Stable Bearing group, the movement of L3 and L4 varied by trial; such that the landmarks move from the starting point at 354 vu to 236 vu and 472 vu but remained constant in angle to the goal location. For the Stable Distance group, L3 and L4 landmarks orbited around the circumference of the goal by trial, holding distance to the goal constant (see Figure 3 for landmark movement).

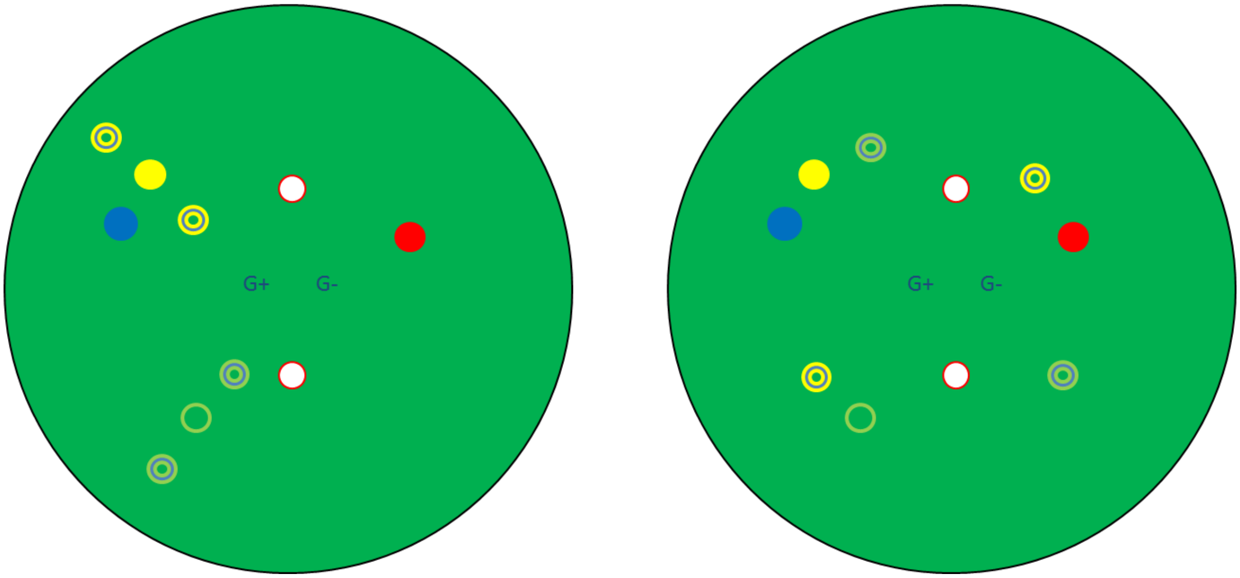

Figure 3. Movement of LMs. Left figure shows Distance group movement, right shows Bearing group movement. Unfilled double circle LM markers are the movement from start denoted by filled/ single circle markers. L0 landmarks markers are white with red outlines, L1 is blue, L2 is red, L3 is yellow, L4 is green.

Testing. There were 7 test trials interspersed throughout the testing phase. Each test trial was 30s in duration with no available goal location. All landmarks during testing were positioned as they are for the control group during training. The first two test trials serve as extinction proof trials, EXT 1 and EXT 2; signaling to the participant that a goal location may not be available on all trials. There are two extinction test trials during Phase 1 (Trials 11 and 15).

The remaining test trials occurred pseudo-randomly throughout Phase 2. There was 1 test trial for each 4 trial block. The initial and last test trials (Added Array Test) consisted of L2, L3, and L4 only. These test trials assessed blocking of the added array by the acquisition array, as well as the stability of learning throughout the experiment. The following test trials include one of the added landmarks paired with the two L0 landmark array. The test trials consisted of L2, L3, or L4 paired with both L0 (named Stable L2 test, Unstable L3 test, and Unstable L4 test respectively). The Unstable L3 test is intended to assess the validity of the MBH. Such that L3 does not add a unique bearing to the goal as it is placed close to L1 in the Control and Stable Bearing groups. These test trials were counterbalanced across participants to ensure that there is no effect of test placement, resulting in a total of 6 arrangements per group.

Data Analysis

The location of the participant was recorded in Cartesian coordinates (x,y) once per second throughout each 30-s test trial and these records served as the raw data for all analyses. Particular areas of the Cartesian grid were defined as the Correct, Incorrect and Other areas. The Correct area formed a rectangle that extended west from each L0 landmark and included the trained-goal area (see Figure 4). The Incorrect area was equal in size to the Correct area, but extended east of the L0 landmarks. The Other area included all of the area not included in either the Correct or Incorrect areas.

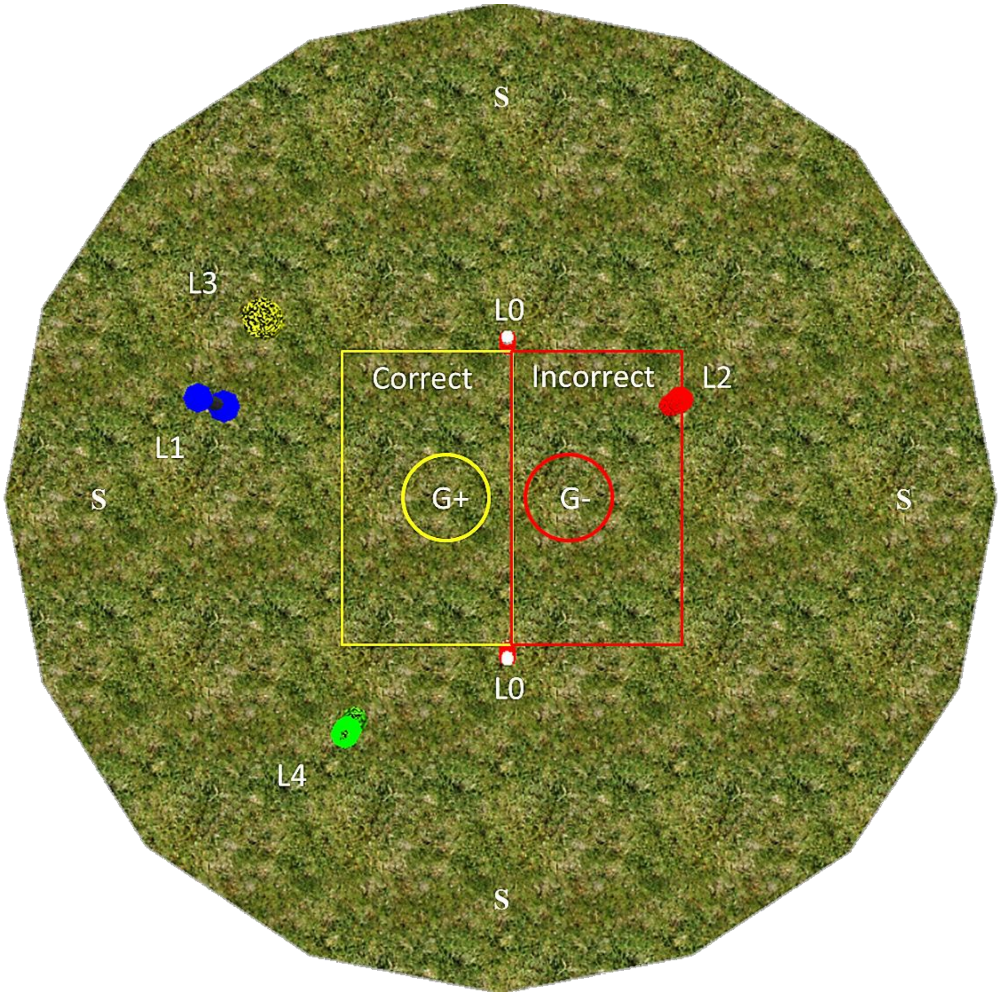

Figure 4. Birds-eye view of Correct and Incorrect areas.

The accuracy of search was measured in three ways for each trial for each participant. The first was the proportion of time spent in the Correct area during each test trial. This measures the rate and accuracy of search in the G+ area. The second was the preference ratio, which was a measure of the relative amount of time spent in the Correct and Incorrect areas. The preference ratio was calculated as

$$Preference = \frac{T_C}{T_C + T_I}$$

where T_C is the time in the Correct area and T_I is the time in the Incorrect area. This is a measure of location discrimination of the G+ from G-. The last measure was a measure of distance error.

Distance error was computed by measuring the length of the line between the center of the trained-goal area and the participants' first "choice" in each test trial. A choice was defined as remaining in the same location for three full seconds, consistent with the required dwell duration during training trials. This test measures the uncertainty of first "choice" among participants..

Separate analyses were conducted for each dependent measure. For each measure, the data were submitted to a mixed model analysis of variance (ANOVA) with Group (Control, Bearing, Distance) as the between-subjects factor and Trial-Type (various) as the within-subjects factor. Alpha (α) was set at 0.05 for all analyses, and all analyses were conducted using SPSS statistical analysis software.

Chapter 5

Results

Phase 1 Tests

To assess the level of performance at the end of Phase 1, performance in the extinction tests was analyzed. The proportion of time in the Correct location (accuracy), preference ratio (location discrimination), and distance error (uncertainty) were submitted to separate mixed ANOVAs with Group (Control, Bearing, Distance) as the between-subjects factor and Trial Type (EXT 1, EXT 2) as the within-subjects factor. The proportion of time spent in the Correct area during EXT 1 (*M* = .49, *SEM* = .04) did not differ from EXT 2 (*M* = .55, *SEM* = .04), *F* (1, 32) = 2.86, *p* = .10. Additionally, the Bearing (*M* = .52, *SEM* = .05*)*, Distance (*M* =.43, *SEM* = .05*)* and Control (*M* = .61, *SEM* = .05) groups did not differ in their accuracy during extinction trials, *F* (2, 32) = 3.16, *p* = .06. There was no interaction, *F* (2, 32) = .91, *p* = .42 (see Figure 5, top panel).

The analysis of preference ratio also revealed no differences in location discrimination between EXT 1 (*M* = .80, *SEM* = .04) and EXT 2 (*M* = .81, *SEM* = .05), *F* (1, 32) = .09, *p* = .77. Additionally, the Bearing (*M* = .81, *SEM* = .06), Distance (*M* = .71, *SEM* = .07) and Control (*M* = .89, *SEM* = .06) groups did not differ, *F* (2, 32) = 1.98, *p* = .15. There was no interaction, *F* (2, 32) = 1.05, *p* = .36 (see Figure 5, middle panel).

The analysis of distance error from the goal location also revealed no differences in uncertainty between EXT 1 (*M* = 111.31, *SEM* = 16.95), and EXT 2 (*M* = 115.44, *SEM* = 21.49), *F* (1, 32) = .87, *p* = .87. Also, the Bearing (*M* = 128.07, *SEM* = 25.88), Distance (*M* = 112.75, *SEM* = 27.03) and Control (*M* = 99.31, *SEM* = 25.88) groups did not differ from each other, *F* (2, 32) =.31, *p* = .74. There was no interaction, *F* (2, 32) = .64, *p* = .53 (see Figure 5, bottom panel).

These analyses revealed that there were no between-groups differences on training, suggesting that each group of participants learned the task to an equivalent level. As such, the performance on the extinction tests were averaged and served as a measure of baseline performance. This baseline (EXT Mu) was used as a comparison point for the Phase 2 test analyses to determine any differences between training and testing.

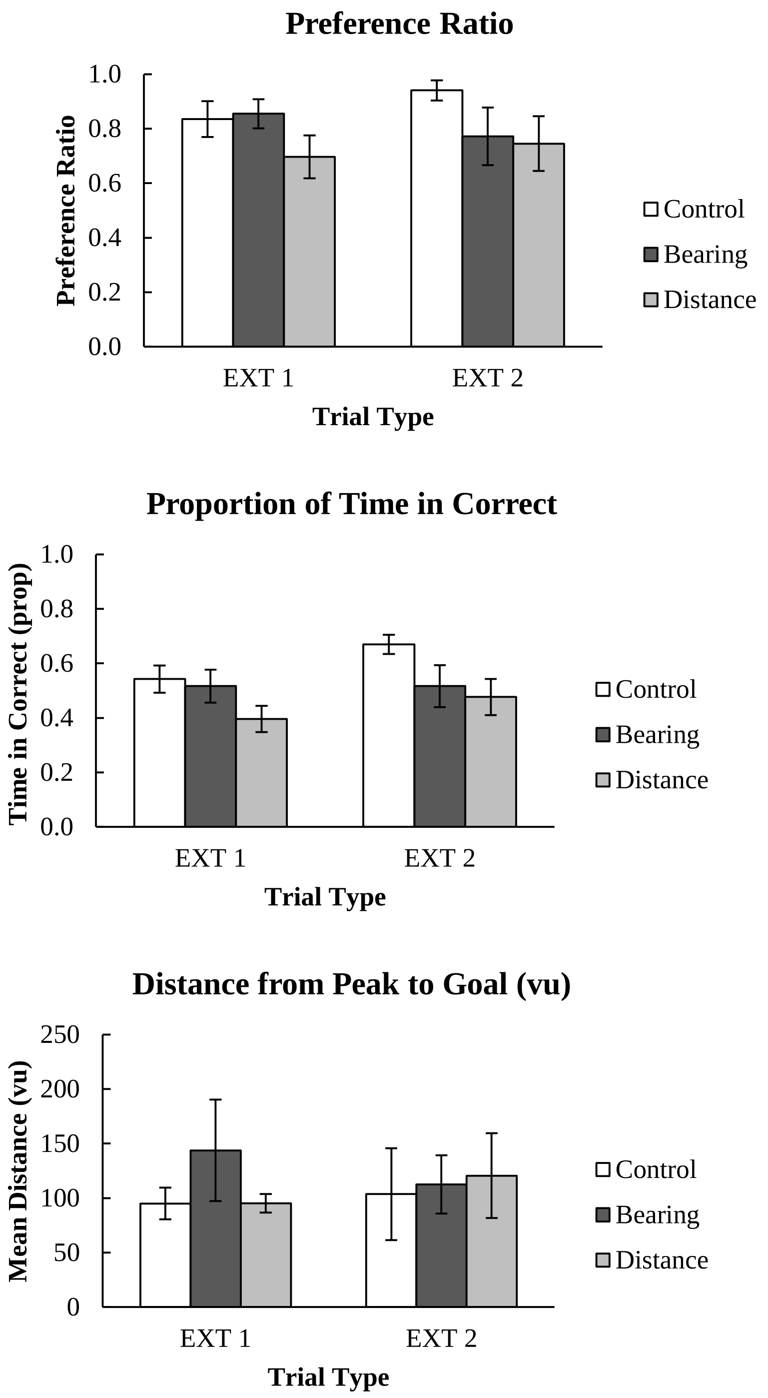

Figure 5. Comparison of EXT 1 and EXT 2 by Group. Top: Mean time spent in Correct by Trial-Type across Groups. Middle: Mean preference ratio by Trial-Type across Groups. Bottom: Mean distance error from peak by Trial-Type across Groups.

Phase 2 Tests

Added-Landmark Tests. Separate mixed ANOVAs with Group (Bearing, Distance, Control) and Trial Type (EXT Mu, Added 1, Added 2) were conducted for each measure. The analysis of proportion of time in the Correct location revealed a main effect of Trial Type, *F* (2, 66) = 8.91, *p* <.001. Planned comparisons revealed that accuracy in EXT Mu (*M* = .52, *SEM* = .03) was significantly greater than in both Added 1 (*M* = .41, *SEM* = .04), *p* = .001, and Added 2 (*M* = .39, *SEM* = .04) tests, *p* < .001, but Added 1 and Added 2 did not differ, *p* = .73. There were no differences in accuracy between the Bearing (*M* = .46, *SEM* = .05), Distance (*M* = .38, *SEM* = .05), or Control (*M* = .48, *SEM* = .05) groups, *F* (2, 33) = 1.37, *p* = .27, and there was no interaction, *F* (4, 66) = 1.40, *p* = .24 (see Figure 6, Top panel).

The analysis of Preference Ratio revealed a main effect of Trial-Type, *F* (2, 66) = 8.67, *p* < .001. Planned comparisons revealed that the preference ratio in Added 2 (*M* = .61, *SEM* = .05) was significantly less than in Added 1 (*M* = .76, *SEM* = .05), *p* =.01, and the EXT Mu (*M* = .81, *SEM* = .04), *p* = .00, but Added 1 and EXT Mu did not differ, *p* = .19. There were no differences in location discrimination between the Bearing (*M* = .76, *SEM* = .06), Distance (*M* = .70, *SEM* = .06) or Control (*M* = .72, *SEM* = .06) groups, *F* (2, 33) = .22, *p* = .80, and there was no interaction, *F* (4, 66) = 1.61, *p* = .18 (see Figure 6, Middle panel).

The analysis of distance error from the goal revealed that there were no differences in uncertainty between Added 1 (*M* = 162.06 *SEM* = 24.97), Added 2 (*M* = 133.65, *SEM* = 21.36) or EXT Mu (*M* = 110.61, *SEM* = 14.97), *F* (2, 66) = 1.97, *p* = .15. There were no uncertainty differences between the Bearing (*M* = 153.09, *SEM* = 25.10), Distance (*M* = 138.00, *SEM* = 25.10) and Control (*M* = 115.25, *SEM* = 25.10) groups, *F* (2, 33) = .58, *p* = .57, and there was no interaction, *F* (4, 66) = .71, *p* = .59 (see Figure 6, Bottom panel).

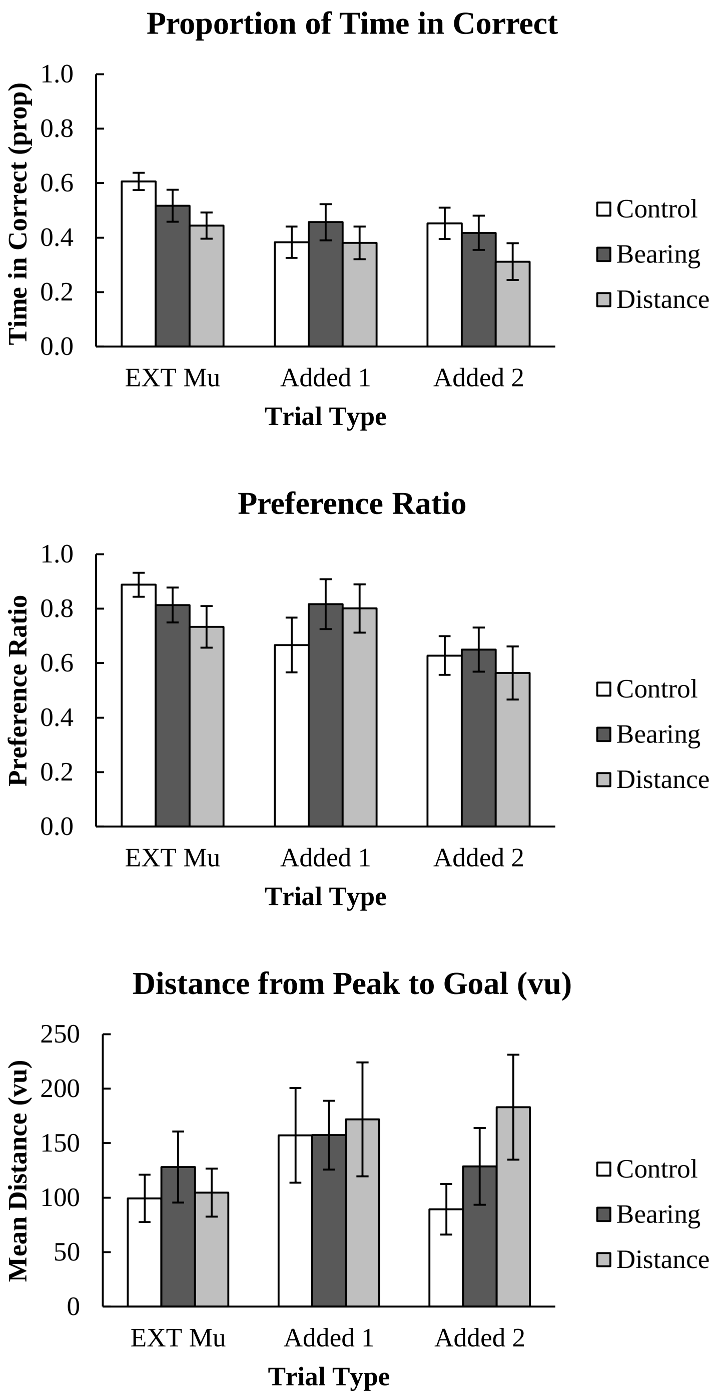

Figure 6. Comparison of EXT Mu to Added 1 and Added 2 by Group. Top: Mean time spent in Correct by Trial-Type across Groups. Middle: Mean preference ratio by Trial-Type across Groups. Bottom: Mean distance error from peak by Trial-Type across Groups.

Individual Landmark Analyses

Time in Correct. One participant in the Distance group was removed from these analyses due to a lack of movement during the L2 test. As such, data from all 12 participants in the Bearing and Control groups and from 11 participants in the Distance group was analyzed. Proportion of time spent in the Correct location was analyzed with Group (Bearing, Distance, and Control) as the between-subjects factor, and Trial-Type (EXT Mu, L2, L3, L4) as the within-subjects factor. There was no effect of Trial-Type, F (3, 96) = .91, p = .44. Search accuracy did not differ across EXT Mu (M = .52, SEM = .03), L2 (M = .53, SEM = .03) L3, (M = .46, SEM = .04) and L4 (M = .51, SEM = .04) trials. Analysis revealed a main effect of Group, F (2, 32) = 6.15, p <.007. Specifically, the Distance group (M = .40, SEM = .04) spent less time in the Correct area than Control (M = .60, SEM = .04), p < .002, but did not differ from the Bearing group (M = .51, SEM = .04), p = .06. There was no interaction, F (6, 96) = .35, p = .91(see Figure 7, Top panel).

Preference Ratio. Preference for the Correct location was analyzed with Group (Bearing, Distance, and Control) as the between-subjects factor and Trial-Type (EXT Mu, L2, L3, L4) as the within-subjects factor. There was no effect of Trial-Type, F (3, 96) = .64, p = .59. There were no differences between L2 (M = .76, SEM = *.04*), L3 (M = .73, SEM = .05), L4 (M = .76, SEM = .05), or EXT Mu (M = .81, SEM = .04). Analysis revealed a main effect of Group, F (2, 32) = 7.58, p < .003. The Distance group (M = .62, SEM = .05) showed poorer location discrimination than the Bearing group (M = .80, SEM = .04), p <.007, and the Control group (M = .86, SEM = .04), p <.002. There was no interaction, F (6, 96) = .80, p = .57 (see Figure 7, Middle panel).

Distance Error. Distance error from the goal was analyzed with Group (Bearing, Distance, and Control) as the between-subjects factor and Trial-Type (EXT Mu, L2, L3, L4) as the within-subjects factor. There was no effect of Trial-Type, *F* (3, 96) = .97, *p* = .41. Distance errors were similar during L2 (*M* = 95.39, *SEM* = 10.96), L3 (*M* = 118.66, *SEM* =14.98), L4 (*M* = 112.76, *SEM* =14.77), and EXT Mu (*M* = 110.43, *SEM* = 15.43). There were no differences between groups, *F* (2, 32) = 1.57, *p* = .23. The Bearing (*M* = 110.96, *SEM* =19.02), Distance (*M* = 132.73, *SEM* = 19.87), and Control (*M* = 84.24, *SEM* =19.02) groups did not differ, *p*s > .05 (see Figure 7, Bottom panel).

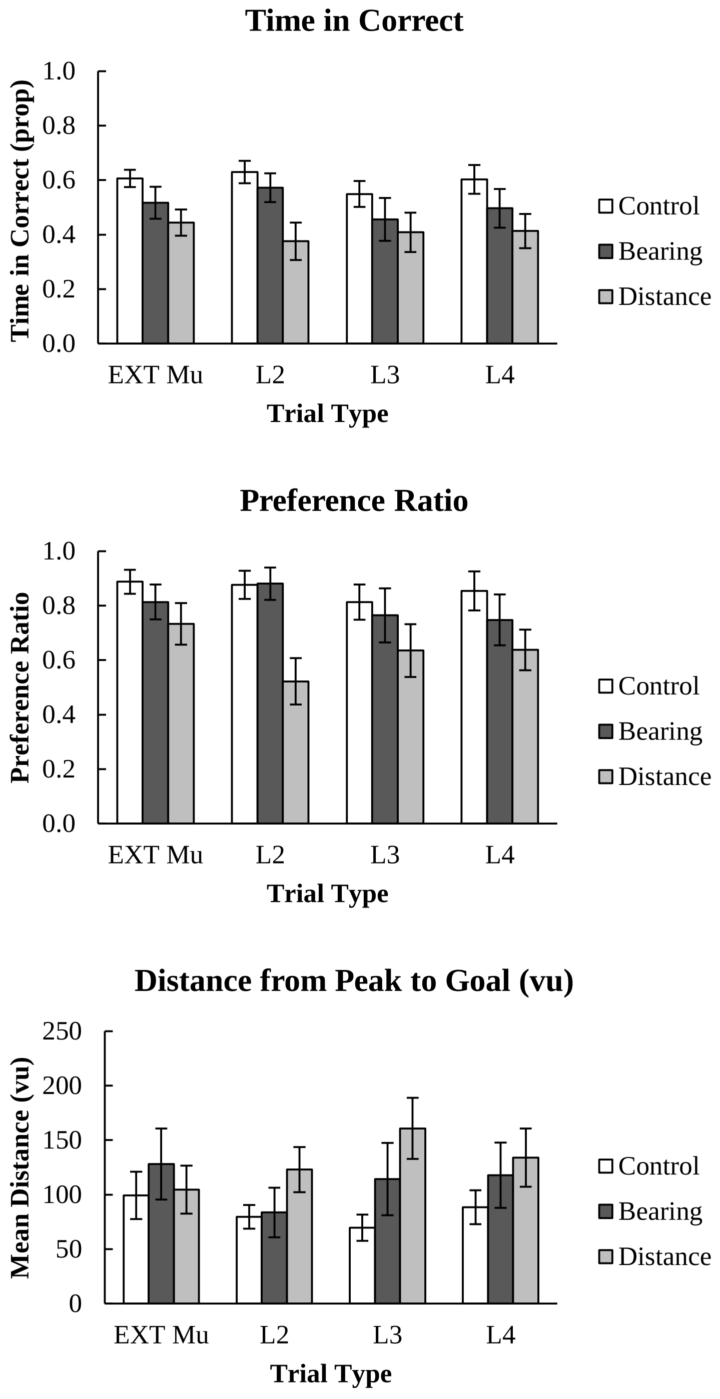

Figure 7. Comparison of EXT Mu to L2, L3, and L4 by Group. Top: Mean time spent in Correct by Trial-Type across Groups. Middle: Mean preference ratio by Trial-Type across Groups. Bottom: Mean distance error from peak by Trial-Type across Groups.

Chapter 6

Discussion

Phase 1. Participants in all groups (Bearing, Distance, and Control) learned the task similarly. There were no differences between groups or across EXT 1 and EXT 2 tests. Stable performance on the Phase 1 tests shows that all groups learned the relationship between the three-landmark array and the goal. High accuracy, location discrimination, and low uncertainty suggest that participants reached asymptote with the training array before introduction of the Added landmarks in Phase 2. As such, these measures were averaged across extinction trials for each group to provide a measure of baseline performance (EXT Mu).

Phase 2. Added-Landmark Tests. The Added tests 1 and 2 results showed that participants did not learn about the Added LMs as well as the EXT Mu. The Time in Correct measure showed that there were no differences in accuracy between Added 1, and Added 2. However, participants were less accurate during Added 1 and Added 2 tests than the EXT Mu. The Preference Ratio measure revealed that there was poorer location discrimination in the Added 2 test than in Added 1 or EXT Mu, but Added 1 and EXT Mu did not differ. This difference could be due to the start position of participants in the Added 2 test in the East of the environment. This could have caused participants to walk through the G- area in order to reach the G+ area. The results from the Time in Correct analysis showed that neither test showed persistent search in the goal location, despite the fact participants showed higher location discrimination for the goal location in the first Added test.

The Distance Error results revealed no differences in uncertainty across Trial-Type or group. Though the uncertainty differences between groups did not reach statistical significance, the Distance group trended toward greater distance errors than the Bearing and Control groups.

There is a great amount of distance error in the Added test data. Participants seem to be narrowing their search toward the center of the environment. However, the error from the goal as compared to the EXT Mu is larger. There is a possibility that the uncertainty is due to some effects of blocking. The variability in the Distance error analysis for the Individual tests is large as well. The groups are not significantly different from each other, nor are there statistical differences between Trial-Types; however, inspection of the error shows great variability. While this may be a function of the distance and bearing errors, the large variability could be why there are no significant differences between groups or Trial-Type in the Distance Error analyses.

Individual Landmark Tests. The Time in Correct analyses showed that the Distance group was less accurate than the Control group, but not the Bearing group. In addition, the Preference Ratio showed that the Distance group discriminated between locations more poorly than the Bearing and Control groups. The failure of the Distance group to reliably find the goal location could be due to the instability of the Phase 2 landmarks. The Distance group was presented with L3, and L4 moving around G+ across trials. Timberlake, Sinning, and Leffel, (2007) and Biegler, and Morris (1996), found that instability of landmarks in an environment will greatly affect learning. Current results agree with the previous research suggesting that instability of landmarks within an environment will decrease the amount learned about each added landmark.

The lack of differences between the Individual Tests and EXT Mu agree with previous research investigating spatial blocking paradigms. Specifically, Alexander, Wilson, and Wilson (2007) showed that in a barren environment, added landmarks will be learned. Further, Biegler and Morris (1999) showed that learning of added landmark positions can occur. The current results agree that the position of the landmarks is equally as important as the stability of landmarks for learning to occur. The Distance group’s lower Preference and Time for Correct than the Bearing and Control groups could be explained by the inability of participants to form a stable array with respect for the goal. There were no differences between the Control and Bearing groups, suggesting that stability within the environment allows for a stable landmark array can be formed to reliably locate the goal.

Model Comparison

According to the assumptions of the Associative model, as posed by Rescorla and Wagner (1972), any added landmarks will be blocked by the initial array. Results in the Added and Individual landmark tests would have shown less preference and location discrimination for the Correct than EXT Mu across testing if the Associative account was able to explain this type of spatial learning. The differences between Added 1 and Added 2 in Preference for the goal suggest that the Phase 1 landmarks did not block learning about the Added landmarks across the experiment as is seen in performance in the Added 1 test. However, the accuracy of search in the Correct location showed evidence of blocking during Added 1 and 2 as compared to EXT Mu.

However, blocking of the added landmarks was not represented in the results from the Individual tests. The Associative theory can only explain these results by suggesting that the Phase 1 landmarks were guiding participants' search toward the goal location. However, there were no differences between the individual tests and the EXT Mu, and the L0 landmarks were ambiguous as to the G+ location. If participants were using only the L0 landmarks to guide their search, they would have shown poorer location discrimination, or lower accuracy, as compared to the EXT Mu. Specifically, the lack of differences between the Individual tests shows that participants are learning about landmarks added to the initial array. Rescorla and Wagner (1972) stressed the importance of contiguity and contingency of the relationship between the landmarks and goal. Though according to the Associative theory, the Individual tests would have revealed differences between the baseline performance and tests.

The current results show mixed evidence of blocking in accordance with the Associative theory. The accuracy of search in the Correct area during the Added tests shows evidence of blocking when the L0 landmarks are not present. However, the persistent search and accuracy seen in the Individual tests do not show evidence of blocking. Participants did not show differences between baseline and tests as performance across Trial-Type was similar. Hayward et al., (2003) pointed out that learning of added landmarks could occur if saliency was similar among landmarks. It is possible that the added landmarks were of similar saliency, and when the two L0 landmarks were available, participants were able to find the Correct area.

The Associative theory can account for the Added test results, but not the Individual test results. The MBH states that added landmarks will be learned if they are equally as salient and have a unique bearing to the goal (Kamil & Cheng, 2001). Participants' search behavior during the Added tests showed a trend toward search in the center of the environment, as there were no differences in peak error of first choice in the Distance Error analyses. In the Individual tests, the lack of differences between accuracy and location discrimination shows that the Added landmarks were unique enough to be learned as well as baseline, in the presence of the L0 landmarks. Participants in the Control group learned the Added landmarks as they related to the goal in the Individual tests. The Bearing and Control groups performed better than the Distance group across test trials; however, the other groups learned the individual landmarks equally as well.

A main assumption of the MBH is that distance errors will be greater than bearing errors. Though there are no significant results in uncertainty of first choice, the data show a trend toward Distance showing the most error with Bearing showing more than Control, but less than Distance. Another assumption of the MBH is that the added landmarks must have a unique bearing to the goal. The lack of differences in Trial-Type suggests that either this assumption is not required in an otherwise barren environment, or L3 did have a unique enough bearing to be learned. Sturz and Katz (2009) found that pigeons were able to judge the distances from the landmark to goal. This previous research agrees with the current results that when the landmarks are stable in array, added landmarks can be learned. The Control and Bearing groups were able to reliably estimate the location of the goal. The lack of differences in distance error from first choice shows that although the Distance group showed less accuracy in search at the Correct location, all groups were making similar distance errors in first choice.

The differences in the groups during the Individual tests could be due to the greater instability of the landmarks presented to the Distance group, as compared to the Bearing and Control groups. The Bearing group, while landmarks were unstable, held a constant bearing to the goal. This consistency in relative position could have facilitated learning of the landmarks cardinal position to the goal. The Distance group was not presented with a consistent landmark array, which could have inhibited learning of the relative positions of the Added landmarks to the goal.

Limitations. The differences in the Preference Ratio in Added 1 and Added 2 could have been due to fatigue, as Added 2 was toward the end of the experiment. Another possible reason for the decrease in performance from Added 1 to Added 2 could be the start position of the participants during the Added 2 test. Participants started on the East side of the environment which could have caused them to have to move through the G- location to enter the G+ location. The start position during Added 2 could have caused the results to show less accuracy in search, which may have skewed the data for the preference ratio. The similar persistent search in the Correct location across Added 1 and Added 2 was less than baseline, which suggests evidence of blocking.

Another limitation is that many participants did not enter the precise G+ location, as such; analyses for Preference and Time included the area around the goal location. The analysis of the Preference Ratio had to be increased to include the Correct location and not only the G+ location. Without this increase, the sample sizes would have been greatly unequal, and would have lacked in power. However, the analyses performed revealed differences across groups, and Trial-Types. Even with the increase in the area for analyses, there was one participant in the Distance group that was removed from the Individual landmark tests. This participant did not move from the start position during the L2 test, and so was not included in any of the Individual test analyses. The participant made clear choices during the other tests, and as such, was included in the Added test analyses.

Future research should include individual landmark test trials without the presence of Phase 1 landmarks. The results of that analysis could help to determine what participants are learning about each individual landmark. Sturz and Katz (2009) presented the pigeons in their research with individually trained landmarks. Their results showed that without the presence of other landmarks, the pigeons were still able to locate the goal location. Inclusion of single landmark tests could greatly increase understanding of any effects of blocking of the Individual landmarks. Further this analysis would lead to a greater understanding of what properties participants are learning about the landmark (i.e., bearing and distance estimates).

Conclusions. The results suggest that the Associative Theory may not be able to account for this type of learning. Participants showed evidence of blocking during the Added tests, but participants learned about the added landmarks in the Individual tests. The MBH seems to better account for the results seen through this experiment. In general, the Control group outperformed the Bearing group, which outperformed the Distance group. These results agree with the MBH that distance is harder to estimate than bearing, and added landmarks will be learned so long as they are unique and equally predictive of the goal (Kamil & Cheng, 2001). The results found can help to explain many of the mixed results researchers are finding with blocking paradigms in the spatial domain.

The MBH and the Associative theory are not necessarily mutually exclusive. There are commonalities between the theories Specifically, Rescorla and Wagner (1972) state that the landmark-to-goal relationship must share contiguity and contingency in order to be learned successfully. Kamil and Cheng (2001) agree, stating that the initial and added array must share contiguity and contingency for added landmarks to be learned. Further, the MBH states that the added landmarks must have a unique bearing to be learned. The Associative theory states that landmarks of different saliency, including the amount of information added to the array, will affect the associative strength of each landmark (Rescorla, & Wagner, 1972). Future research with blocking paradigms should take into account the commonalities between these two competing theories when drawing conclusions.

Humans are navigating an ever-changing environment daily, yet are able to locate their goal with ease. These results are indicators of how humans are learning about their environments, and their ability to rely on unstable landmarks enough to locate a goal reliably. Anyone trying to find their way can use these results; from military personnel in barren environments to people rearranging shopping locations in the busiest of malls. Military personnel need not rely on only stable landmarks, but on landmarks that provide a stable frame of reference (i.e., stable distance, or bearing). People are paying attention to and learning about almost everything in their environments, so long as they share contiguity and contingency to the goal. Humans will use anything available to find their way, and will base their search (for home, goods, etc.) on the environmental landmarks available.

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