Summer 2017

Examining the Effects of Enclosure Size at Training and at Test in Spatial Reorientation

Zebulon K. Bell

EXAMINING THE EFFECTS OF ENCLOSURE SIZE AT TRAINING AND AT TEST IN SPATIAL REORIENTATION

by

ZEBULON KADE BELL

(Under the Direction of Bradley Sturz)

ABSTRACT

Previous research has begun to shed light on the differentiated influence of enclosure size on cue use during reorientation (Sturz, Forloines, & Bodily, 2012). Namely, the question remains of why both feature (i.e., objects or landmarks in the enclosure) and geometric (i.e., shape of the enclosure) cues are differentially affected by enclosure size, and the extent to which local (i.e., wall lengths and corner angles) and global (i.e., principal axis of space) geometric cues are affected by enclosure size. Further, it remains unclear whether training size, testing size, or the relationship between training and testing size influences the use of local geometric cues. In the present study, we trained participants to respond to a goal location in differently-sized trapezoidal enclosures (requiring use of both local and global geometric cues). Our design allowed us to hold training size constant while manipulating testing size, hold testing size constant while manipulating training size, and examine the potential influences of the relationship between training and testing size (increasing in size from training to testing or decreasing in size from training to testing). We then tested participants in differently-sized rectangular and parallelogram-shaped enclosures (rectangular to isolate the use of the principal axis of space and parallelogram to place locations specified by the principal axis and corner angles in conflict). Our results suggest that enclosure size influenced the use of local geometric cues but not global geometric cues but only with respect to the relationship between training and testing environments.

INDEX WORDS: Spatial reorientation, Spatial navigation, Enclosure size, Virtual environments, Incidental learning

EXAMINING THE EFFECTS OF ENCLOSURE SIZE AT TRAINING AND AT TEST IN SPATIAL REORIENTATION

by

ZEBULON KADE BELL

B.A., Auburn University, 2014

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

EXAMINING THE EFFECTS OF ENCLOSURE SIZE AT TRAINING AND AT TEST IN SPATIAL REORIENTATION

by

ZEBULON KADE BELL

Major Professor: Bradley R. Sturz
Committee: Kent D. Bodily
Lawrence Locker, Jr.

Electronic Version Approved:
July 2017

ACKNOWLEDGEMENTS

I would like to thank Donald G. Sullens for his help in learning how to use Excel to an "intermediate" level and in running participants, and for his regular conversations dealing with the finer points of psychological science.

I would also like to thank my Thesis Committee, Kent D. Bodily and Lawrence Locker, Jr., and particularly my Committee Chair, Bradley R. Sturz. Their seemingly endless patience, wisdom, and advice helped to make this project both successful and beneficial in my academic career.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

INTRODUCTION

Navigation and Reorientation

Any mobile organism, from ants to humans, must possess some means by which to navigate and orient within their environments. Many organisms rely on resources distant from their home sites, and they must be able to find those resources and then return home. One method utilized by mobile organisms to accomplish this task is landmark-based navigation. Landmarks are defined as any perceptible cue that can be used as a reference point, and landmarks can be segregated into proximal and distal landmarks (Buckley, Smith, & Haselgrove, 2014). Generally, proximal landmarks refer to those near the goal location and distal landmarks refer to those farther from the goal location (Buckley, Haselgrove, & Smith, 2015).

Chapter 2

BACKGROUND LITERATURE

Landmark-Based Navigation

One task designed specifically to isolate the use of distal landmarks is the Morris Water Maze task (Morris, 1981; 1984). In this task, a rat is placed in a circular tank of water. The water is treated with a substance to make it opaque (milk, in the original design), and the rat must find a platform to escape the water. The reward is escape from the water. Importantly, the Morris Water Maze (MWM) can contain intra-maze (proximal) and extra-maze (distal) cues. Cues can be placed on the walls of the pool itself or outside of the maze (Harvey, Brant, & Commins, 2009).

Morris (1981) sought to isolate the use of distal cues for navigation in rats. Using the apparatus described above, he had four groups of rats proceed through three sets of trials: pretraining, escape acquisition, and testing. The four groups were separated into Cue + Place (i.e., a visible proximal cue of the black, above-water, and stationary platform to escape), Place (i.e., a non-visible proximal cue of the milk-white, underwater, and stationary platform to escape), Cue-Only (i.e., a visible proximal cue of the black, above-water, and non-stationary platform to escape), and Group-Random (i.e., a non-visible proximal cue of the milk-white, underwater, and non-stationary platform to escape). Latency to escape across trials, along with swimming routes on the final trials of each rat served as the primary measures of learning. The results showed that the groups Cue + Place, Place, and Cue-Only acquired the task relatively quickly, while Group-Random was much slower. The first three groups also traveled a shorter total distance compared to the random group. These results suggest that rats can utilize distal cues in isolation to navigate.

As with many animal navigation paradigms, human correlates have been developed for comparative purposes by way of a virtual Morris Water Maze task (Schoenfeld, Schiffelholz, Beyer, Leplow, & Foreman, 2017; Sneider, Hamilton, Cohen-Gilbert, Crowley, Rosso, & Silveri, 2015; van Gerven, Ferguson, & Skelton, 2016; Higa, Young, & Geyer, 2016; de Castell, Jenson, & Larios, 2015; Daugherty & Raz, 2017). For example, Schoenfeld et al. (2017) attempted to establish a formal comparative analysis that examined a sample of both mice and humans. Mice were trained and tested in a standard Morris Water Maze as described above, but with four equally-spaced landmarks around the walls of the maze. Humans were trained and tested within a virtual version of this environment, which was represented as a circular island with four equidistant landmarks surrounding it. The primary measure for both species was latency to finding the “goal”. The results showed no major difference between species, and these results support the comparative strength in using a virtual analog for a cross-species comparisons.

Reorientation Paradigm

An important step in any form of navigation is determining direction of travel, and ascertaining one’s current location within an environment is a necessary first step in accurate orientation. First utilized by Cheng (1986), the reorientation paradigm involves first disorienting participants to remove any preexisting sense of direction and then training them to respond to a rewarded location in a rectangular environment marked by distinct cues. After training, aspects of the environment are manipulated to determine their influence on responding. Across four experiments, Cheng (1986) trained rats to respond to a particular corner of a rectangular environment. During testing, various aspects of the rectangular environments were manipulated between training and testing. After a number of forced-correct training trials in which the rats were shown the location of the food, certain aspects of the environment were altered in order to generate cue conflict between geometric cues and featural cues. Geometric cues are typically understood to be any usable cue in the environment involving the shape of the environment, such as points, lines, and angles. Conversely, featural cues are usually considered to be any other cue within the environment such as colored or textured walls, distinct corner panels, or landmarks within the environment (Cheng, 2005). Across all experiments, the geometric cues were held constant while the featural cues were altered, and the results suggested that the rats were primarily utilizing geometric cues. That is, their responses toward the correct goal location and the rotational equivalent (diagonally opposite corner to the correct goal location, which, barring featural or vestibular cues, is indistinguishable from the correct goal location) remained well above chance.

As detailed above in Cheng (1986), researchers typically train the subject or participant to move toward a goal location within a rectangular environment via a specific feature (Cheng & Newcombe, 2005). Once the subjects are trained, the researchers then make various adjustments to the training environments to measure performance and determine the extent to which each adjustment influences the reliance on cue types (Cheng, 2008). As a result of this training, once the initial features are removed and the subjects or participants are placed in a featureless rectangular testing environment, they tend to respond equally to both the trained goal corner and to the opposite or rotationally equivalent corner at above-chance rates (Cheng & Newcombe, 2005). This observed tendency to respond to both the correct "trained" corner and the rotational equivalent corner has been interpreted as evidence for the use of geometric cues during reorientation (Cheng, 2005). As shown in Cheng (1986), systematic responding to the rotationally equivalent location suggests that geometric cues take primacy over feature cues in certain environments.

Feature and Geometry Cue Utilization

Existing research suggests that both feature and geometric cue use can be utilized during reorientation (Cheng and Newcombe, 2005). Similarly, existing research suggests that both local (i.e., wall lengths and corner angles) and global (i.e., principal axis of space) geometric cues are used during reorientation (Bodily, Eastman, & Sturz, 2011; Kelly et al., 2011a; Sturz & Bodily, 2011; Kelly, Durocher, Chiandetti, & Vallortigara, 2011). In an attempt to isolate the use of these two cue types, Bodily et al. (2011) trained two groups of participants to locate a goal location in various testing environments. The manipulation came from the nature of the training offered to each group; one group was trained in an environment with a reliable global cue of the principal axis of space, while the other group was trained in an environment with an unreliable principal axis of space. Both groups were trained in a trapezoid, but whereas one group's principal axis was always reliable (i.e., one goal location using both principal axis and a local geometric cue of corner angles and wall lengths), the other was trained with an unreliable principal axis of space (i.e., the goal location shifted randomly between two locations) thus making the local geometric cues of the corner angles and wall lengths the only consistently useful cue. The results showed that the group trained with a reliable principal axis responded to both global and local cues. The group trained with unreliable principal axis only responded to local cues, as their training environment never facilitated reliable global cue use. In testing, two mirrored parallelogram-shaped enclosures were used; one in which both the global and local geometric cues were aligned, and one in which both the global and local geometric cues were in conflict. When both global and local geometric cues were in conflict, the group trained with an unreliable global geometric cue of the principal axis of space made relatively more use of local geometric cues.

Enclosure Size Effects

It has long been demonstrated in the literature that reorientation performance appears to be affected by the size of the enclosure (Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, Sheridan, & Jones, 2008). Changes in enclosure size from training to test appear to affect the relative contribution of both feature and geometric cues in reorientation (Ratliff & Newcombe, 2008; Sovrano, Bisazza, & Vallortigara, 2005; Sovrano, Bisazza, & Vallortigara, 2007; Vallortigara, Feruglio, & Sovrano, 2005). Basically, feature cues tend to be more influential in larger enclosures, while geometric cues tend to be more influential in smaller enclosures (Miller, 2009). In other words, it would appear that the individual's perception of the environment dictates the influence of each type of cue. In smaller environments, the entire shape is more salient, while in larger environments, the entire enclosure cannot be perceived at a glance and must be processed in a piecemeal fashion based on the perceivable parts (Sturz, 2014).

Given that enclosure size appears to influence the use of geometric and feature cues, one possibility is that local and global geometric cues should be categorized and studied in the same fashion as feature and geometric cues. To address that possibility, Sturz, Forloines, and Bodily (2012) trained two groups of participants to respond to goal locations uniquely specified by both a local geometric cue (specific combination of wall lengths and corner angles) and a global geometric cue (specific side of the principal axis) within a trapezoidal training enclosure. One group was trained in a relatively smaller trapezoidal enclosure while the other was trained in a relatively larger trapezoidal enclosure. Both groups were then tested for reorientation in both small and large rectangular enclosures and parallelogram-shaped enclosures. Rectangular enclosures are used to isolate the use of a global geometric cue, such as the right side of the principal axis of space, by eliminating useful local geometric cues like wall lengths and corner angles. Parallelogram-shaped enclosures are used to place both types of cues—both local (corner angles) and global (principal axis) geometric cues—in conflict, to determine whether one type of cue develops preferential use based on training. Their results showed that both groups (trained in small trapezoid; trained in large trapezoid) acquired the geometric cue, meaning that they both responded to the trained goal location at similar above-chance rates in the rectangular enclosures. However, the parallelogram-shaped testing enclosures showed a distinct difference between training groups such that the group trained in the larger trapezoid responded more to local geometric cues than global geometric cues. That particular finding, when compared with prior literature on featural vs. global cue use, suggests that local geometric cues function similarly to feature cues. In other words, training in larger enclosures tends to promote more local and featural cue dependence compared to training in smaller enclosures. These results were also interpreted to suggest that changes in relative cue use between global and local cues are driven by local cue availability.

Research has yet to determine the source of this effect; specifically, enclosure size appears to influence the use of local but not global geometric cues, but it remains unclear whether training enclosure size or testing enclosure size was the source of the observed effect. Sturz et al. (2012) found that enclosure size appears to affect local geometric cues use but not global geometric cue use, but it remains unclear whether training environment size or the testing environment size influenced the use of local geometric cues.

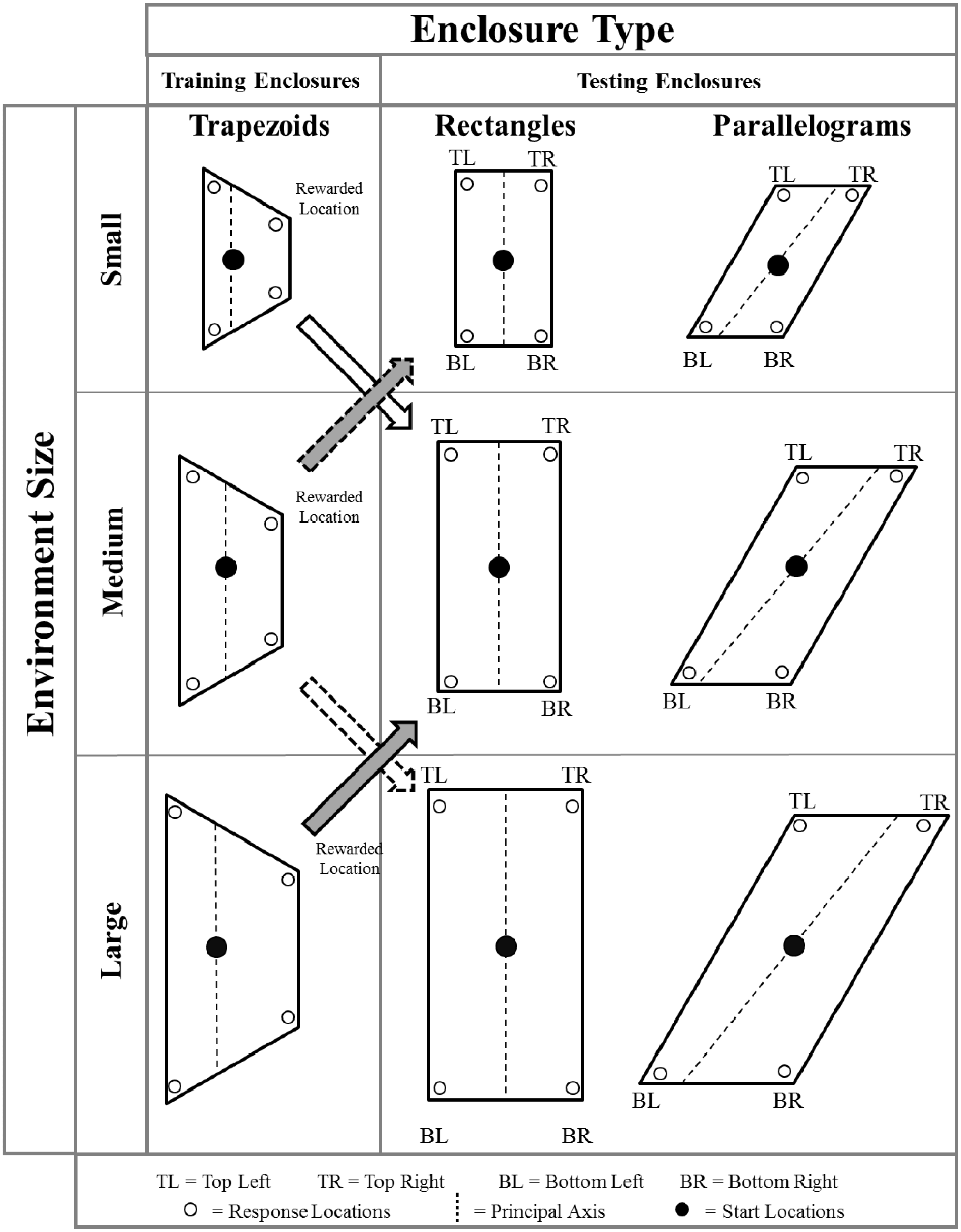
One interesting possibility yet to be considered in the literature is that perhaps it is not training environment size or testing environment size alone but rather the relationship between training size and testing size that influences the use of local geometric cues. To date, research investigating the influence of enclosure size on the use of local geometric cues has focused exclusively on the size of the training environment or the size of the testing environment [i.e., small or large (see Sturz et al., 2012)]. As a result, it remains unknown whether the relationship between the size of the training environment to the size of the testing environment (i.e., environment decreases in size from training to testing or the environment increases in size from training to testing) influences the use of local geometric cues.

Purpose of the Study

The purpose of the present experiment was to isolate whether training size, testing size, or the relationship between training and testing size influences the relative use of local geometric cues. At the outset, participants were randomly assigned to one of four groups balanced by gender: Testing Manipulation – Small (medium training size, small testing size), Testing Manipulation – Large (medium training size, large testing size), Training Manipulation – Small (small training size, medium testing size), and Training Manipulation – Large (large training size, medium testing size). As shown in Figure 1, these groupings could then be collapsed across a number of different variables to examine various effects. Figure 1 illustrates the relationship measure [either increasing environment size between training and testing (Small to Large) or decreasing environment size between training and testing (Large to Small)] and manner in which training size and testing size were constant between groups. The two groups being tested in medium sized environments had their testing environment sizes held constant, while the two groups being trained in medium sized environments had their training environment sizes held constant. Such a design allowed us the flexibility to collapse the individual groupings as necessary to measure numerous variables (enclosure size, enclosure shape, and the relationship between training size and testing size). All participants were trained to respond to an established goal location in variously-sized trapezoidal enclosures, then tested in variously-sized rectangular and parallelogram-shaped testing enclosures (see Sturz et al., 2012). The use of the rectangular enclosures isolated global geometric cue use. The use of the parallelogram-shaped enclosures placed local and global geometric cues in conflict to determine differences in the relative use of local geometric cues.

Given the results of Sturz et al. (2012), participants' use of global geometric cues should not be affected by changes in environment size, since changes in environment size appear to only affect local geometric cue use. As a result, participants' responses to the geometrically correct corners should occur at above-chance rates in rectangular enclosures regardless of training size, testing size, or the relationship between training and testing size.

However, if training environment size is the determining factor in the relative reliance on local geometric cues, then the group trained in the small trapezoid should rely relatively less on the corner angles (a local geometric cue) compared to the group trained in a large trapezoid when tested in a parallelogram-shaped enclosure. In contrast, if testing environment size is the determining factor in the relative reliance on local geometric cues, then the group tested in the large parallelogram testing environment should rely on corner angles more than the group tested in the small parallelogram testing environment. Finally, if the relationship between training and testing size influences the relative use of local geometric cues, then participants in the Small to Large group should rely less on corner angles in the parallelogram-shaped testing environment compared to participants in the Large to Small group.



Enclosure Type
Training Enclosures
Testing Enclosures
Environment Size
Small
Medium
Large
Trapezoids
Rectangles
Parallelograms
Rewarded Location
TL
TR
BL
BR
TL = Top Left
TR = Top Right
BL = Bottom Left
BR = Bottom Right
= Response Locations
= Principal Axis
= Start Locations

Figure 1. The solid arrows show the training-testing pair for the two groups with a constant testing environment size (small training – medium testing, large training – medium testing).

The dashed arrows show the training-testing pair for the two groups with a constant training environment size (medium training – smaller testing, and medium training – larger testing).

The shading of the arrows represents the proposed collapsed groups: unfilled arrows represent the Small to Large group, and filled arrows represent the Large to Small group.

CHAPTER 3

Method

Participants

One hundred forty-eight undergraduate students participated in this experiment (56 males, 92 females). 96 participants met the training criteria of choosing the correct goal location on at least two of the last three training trials and were included in all analyses. The remaining 52 participants were excluded from analyses. Participants received extra class credit or participated as part of a course requirement.

Apparatus

An interactive, dynamic three-dimensional virtual environment was constructed and rendered using Valve Hammer Editor and run on the Half-Life Team Fortress Classic platform. A personal computer, 21" flat-screen liquid crystal display (LCD) monitor, gamepad joystick, and speakers served as the interface with the virtual environment. The monitor (1,152 x 864 pixels) provided a first-person perspective of the environment. Speakers emitted auditory feedback. Experimental events were controlled and recorded using a Half-Life Dedicated Server on an identical personal computer.

Stimuli

Dimensions are long wall(s) x short walls x height and are measured in virtual units (vu). Nine virtual enclosures will be created (see Figure 1): small, medium, and large trapezoid (~4m x ~2m x ~2m x ~2m; ~6m x ~3m x ~3m x ~3m; ~8m x ~4m x ~4m x~4m); small, medium, and large rectangle (~4m x ~2m; ~6m x ~3m; ~8m x ~4m); and small, medium, and large parallelogram (~4m x ~2m; ~6m x ~3m; ~8m x ~4m). All corner angles were 90 degrees in the rectangles. Corner angles in the trapezoids were 60 degrees for both acute angles and 120 degrees for both obtuse angles. Corner angles in the parallelograms were also 60 degrees for both acute angles and 120 degrees for both obtuse angles. All surfaces were white in color with the exceptions of the floors (gray tile) and the ceilings (black). We delineated four response locations within each enclosure (48 x 48 x 48 vu = ~ 1.2 x 1.2 x 1.2 m), but response locations were not visible to participants.

Procedure

Participants were instructed to navigate to the location that transported them to the next virtual room and to move via the joystick on the gamepad: joystick up (forward), joystick down (backward), joystick left (rotate view left), and joystick right (rotate view right). Simulated eye height was 68 virtual units (~1.73 m). Participants selected a location by walking into it. Selection of a rewarded location resulted in auditory feedback (bell sound) followed by a 7-s intertrial interval (ITI) in which the monitor blacked out and participants progressed to the next trial. Selection of a nonrewarded location resulted in no auditory feedback, and required participants to continue searching until the rewarded location was found. Depending on the participant’s training enclosure size (either a small, medium, or large trapezoid), each participant was exposed to a total of two testing enclosures (one rectangle and one parallelogram).

We attempted to investigate the effects of a changing environmental size in two ways: manipulating the relationship between training and test, and manipulating which environment was held constant between training and test. One group had their environment size decrease from training to test, and the other group had their environment size increase from training to test. This attempted to isolate any differences of the relationship between training and testing environments. Secondly, we manipulated which environment was held constant between groups by randomly assigning one group to have differing training sizes transition into a constant testing size, and by randomly assigning the other group to have a constant training size transition in to differing testing sizes.

We randomly assigned all participants to three different sizes of trapezoidal enclosures for the entirety of their individual training trials such that the small trapezoid had $n = 24$ participants, the medium trapezoid had $n = 48$ participants, and the large trapezoid had $n = 24$ participants. Those trained in the medium-sized trapezoid were further assigned such that half were tested in the small rectangle and parallelogram and the other half were tested in the large rectangle and parallelogram. As a result, this group served to hold training size constant while manipulating testing size. All participants trained in the small trapezoid were tested in the medium rectangle and parallelogram, and those trained in the large trapezoid were also tested in the medium rectangle and parallelogram. As a result, this group served to hold testing size constant while manipulating training size.

Importantly, in this design half of the participants were exposed to constant training sizes between groups but different testing sizes, and the other half were exposed to different training sizes but constant testing sizes between groups. As importantly, in this design, half of the participants were exposed to an increasing relationship between training and test (i.e., trained in small, tested in medium and trained in medium, tested in large) and the other half of the participants were exposed to a decreasing relationship between training and test (i.e., trained in medium, tested in small and trained in large, tested in medium).

Training

Training consisted of 12 trials. Participants were randomly assigned to one of three training sizes: small trapezoid, medium trapezoid, and large trapezoid. These groups could then be collapsed according to either the environment manipulated (either training or test) and/or the relationship between training and testing environments (increasing or decreasing). The gender and number of participants was balanced across groups. For all groups, the location in the top-right corner was designated as the rewarded location such that searching at the egocentric right-hand side of the principal axis and at a location specified by the feature cues of short wall left, short wall right, and obtuse corner angle was rewarded (see Figure 1 above, “rewarded location”). Participants started each trial at the center of their respective training trapezoid (see Figure 1 above, black filled circle). Participants entered their respective training trapezoid at random orientations from 0 degrees to 270 degrees in increments of 90 degrees.

Testing

Testing consisted of 40 trials composed of 10 four-trial blocks. Each trial block was composed of three training trials and one test trial. The order of the training and test trials was randomized within each block. For each test trial, one of six enclosures was presented: small rectangle, medium rectangle, large rectangle, small parallelogram, medium parallelogram, or large parallelogram. The participant’s training enclosure size determined which size testing enclosures were utilized (e.g., small training – medium testing, large training – medium testing, medium training – smaller testing, and medium training – larger testing). Participants were allowed one response per test trial, with no auditory feedback given regardless of the response. After the participants’ responses on the test trials, they experienced the same 7-s ITI as before and then progressed to the next trial. Participants entered all enclosures during testing in the center of the enclosures (see Figure 1 above, black filled circle) at random orientations from 0 degrees to 270 degrees in increments of 90 degrees.

CHAPTER 4

Results

Training

As shown in Figure 2, participants learned to respond to the rewarded location by the end of training to an equivalent level of accuracy. To investigate any potential differences in acquisition due to differences in training environment size, we conducted a three-way mixed analysis of variance (ANOVA) on proportion of correct first choices with Gender (male, female), Training Size (Small, Medium, Large), and Trial Block (1-4) as factors which revealed only a main effect of Trial Block, $F(3, 270) = 66.11$, $p < .001$, $\eta p2 = .42$. None of the other main effects or interactions were significant, Fs < 2.9, ps > .05. Least significant difference (LSD) post hoc tests on the Trial Block factor revealed that all four trial blocks were significantly different from each other (ps < .001). All trial blocks were also significantly greater than what would be expected by chance (i.e., .25), as confirmed by one-sample t-tests, ts(95) > 2.9, ps < .01. Given that there were no statistically significant differences among the three training sizes, we conducted the following analyses to investigate whether our previously described testing groupings would show any effects on acquisition.

Figure 3 shows the mean proportion of participants' correct first choices plotted by three-trial blocks for the twelve trials of Training for the Smaller-to-Larger group and the Larger-to-Smaller group. As shown, participants in both groups learned to respond to the rewarded location (i.e., correct location) at an equivalent rate and terminal level of accuracy by the end of Training. These results were confirmed by a four-way mixed ANOVA on proportion of correct first choices with Gender (male, female), Training/Testing Relationship (Smaller-to-Larger, Larger-to-Smaller), Environmental Manipulation (Training, Testing), and Trial Block (1-4) as factors and revealed only a main effect of Trial Block, $F(3, 264) = 82.36$, $p < .001$, $\eta_p^2 = .48$. None of the other main effects or interactions were significant, *F*s < 3.9, *p*s > .05. Least significant difference (LSD) post hoc tests on the Trial Block factor revealed that all four trial blocks were significantly different from each other (*p*s < .001). All trial blocks were also significantly greater than what would be expected by chance (i.e., .25), as confirmed by one-sample t-tests, *t*s(95) > 2.9, *p*s < .01. We compare participants' performance against chance to measure whether they learned the task. If their performance is not significantly greater than chance, we cannot assume that they learned the intended task. Chance is considered to be .25 in this case because there are 4 possible choices, with only one of them being correct.

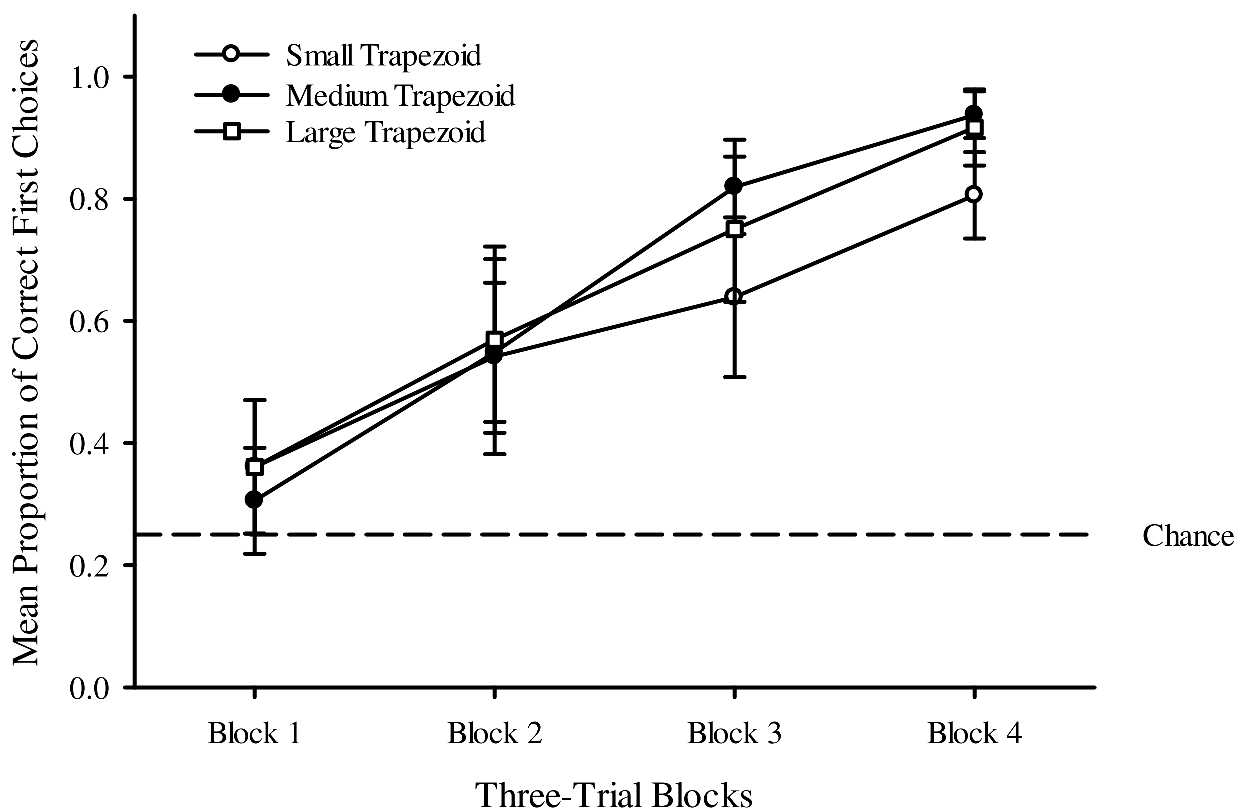


Figure 2. Mean proportion of participants' correct first choices plotted by three-trial blocks for the twelve trials of Training for the three different sizes of training environments. Dashed lines represent chance performance. Error bars represent 95% confidence intervals of the means.

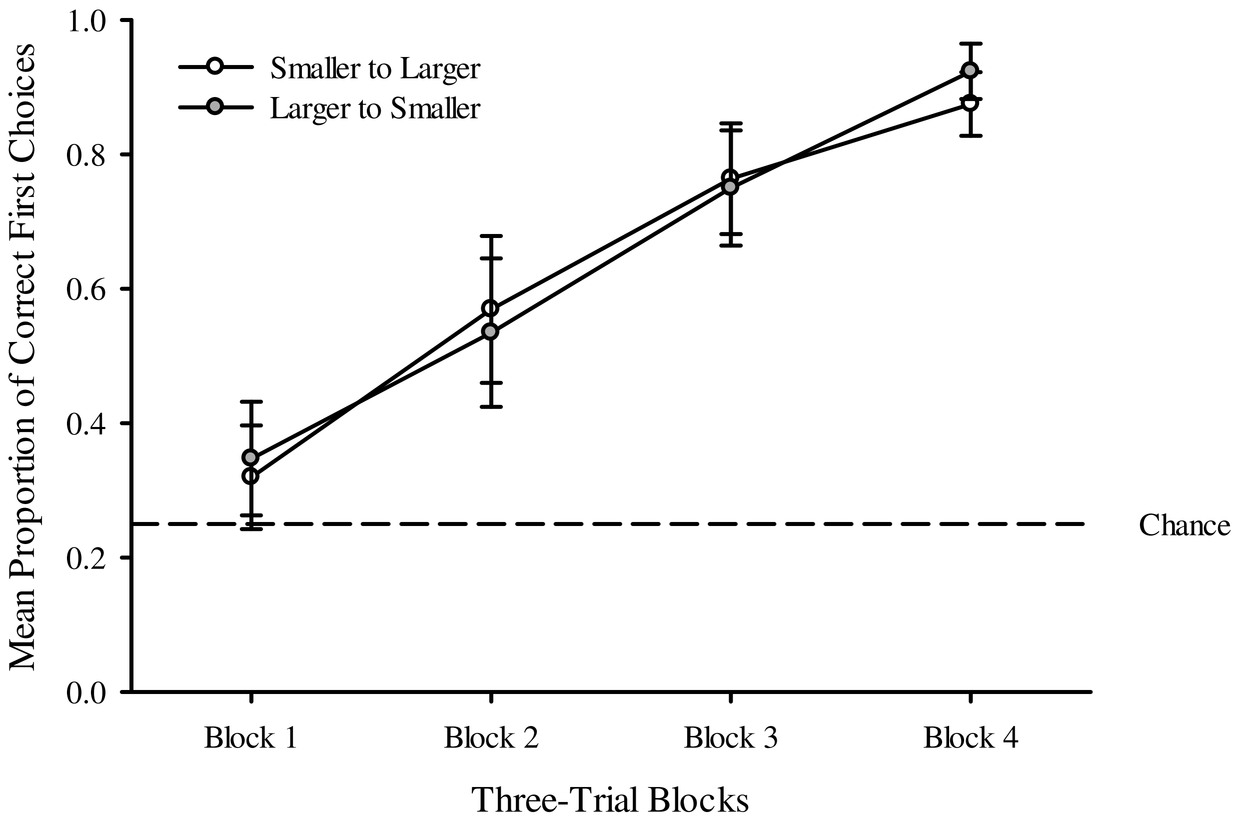


Figure 3. Mean proportion of participants' correct first choices plotted by three-trial blocks for the twelve trials of Training for both groups collapsed into relationship between training size and testing size. Dashed lines represent chance performance. Error bars represent 95% confidence intervals of the means.

Testing

Figure 4 shows the mean proportion of choices to top right and bottom left locations (i.e., geometrically correct locations) plotted by Enclosure Type for both those participants who experienced an increase in enclosure size from Training to Testing (i.e., Smaller-to-Larger) and those who experienced a decrease in enclosure size from Training to Testing (i.e., Larger-to-Smaller). We conducted a four-way mixed ANOVA on mean proportion of choices to geometrically correct locations (i.e., Top-Right and Bottom-Left) with Gender (male, female), Training/Testing Relationship (Smaller-to-Larger, Larger-to-Smaller), Environmental Manipulation (Training, Testing), and Enclosure Type (rectangle, parallelogram) as factors. The ANOVA revealed a main effect of Gender, $F(1, 88) = 6.34$, $p < .05$, $\eta_p^2 = .06$, Enclosure Type, $F(1, 88)$, = 82.46, $p < .001$, $\eta_p^2 = .48$, and a significant Training/Testing Relationship x Enclosure Type interaction, $F(1,88) = 11.06$, $p < .01$, $\eta_p^2 = .11$. None of the other main effects or interactions were significant, *F*s < 3.4, *p*s > .06. Although males ($M = .52$; *95% CI* = .06) allocated a greater proportion of choices to geometrically correct locations compared to females ($M = .41$, *95% CI* = .07), Gender did not interact with any of the other factors. As a result, we collapsed across gender for all additional follow-up tests.

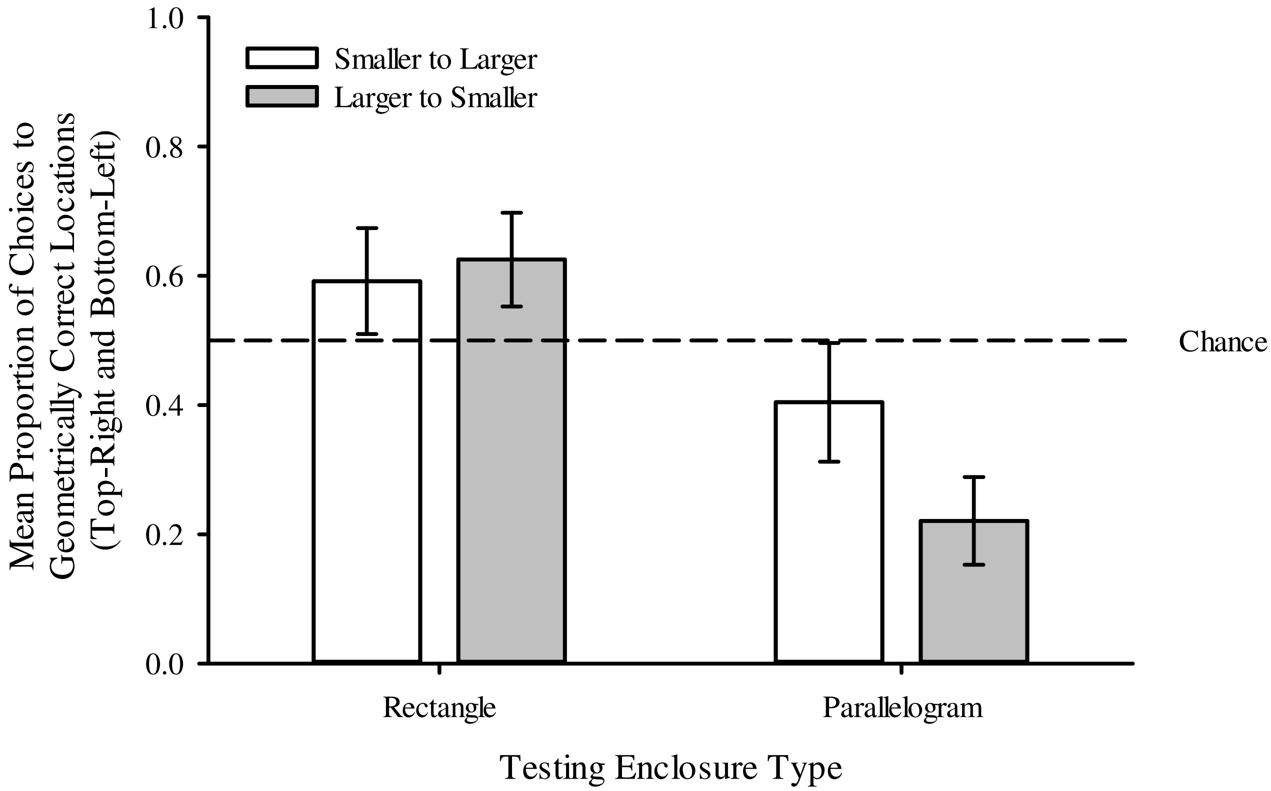


Figure 4. Mean proportion of choices to Top-Right and Bottom-Left locations (i.e., geometrically correct locations) for both groups plotted by enclosure type. Dashed lines represent chance performance. Error bars represent 95% confidence intervals of the means.

To isolate the source of the Training/Testing Relationship x Enclosure Type interaction, we conducted separate independent-samples *t*-tests comparing the Smaller-to-Larger group to the Larger-to-Smaller group for each Enclosure Type. In the Rectangle, there was no significant difference between mean proportion of choices to geometrically correct locations for the Smaller-to-Larger group and the Larger-to-Smaller group, $t(94) = -0.61$, $p = .54$; however in the Parallelogram, the Smaller-to-Larger group allocated more choices to geometrically correct locations as compared to the Larger-to-Smaller group, $t(94) = 3.23$, $p = .002$. As importantly, both groups allocated more choices to geometrically correct locations in the Rectangle than would be expected by chance (i.e., .5), as confirmed by one-sample t-tests, $ts(47) > 2.24$, $ps < .05$. In addition, both groups allocated fewer choices to geometrically correct locations in the Parallelogram than would be expected by chance, as confirmed by one-sample t-tests, $ts(47) < -2.1$, $ps < .05$. In this case, chance was .50 due to there being 4 possible choices and 2 possible correct choices.

CHAPTER 5

Discussion

All participants regardless of training size learned to respond to the rewarded location during training trials, thus showing that they learned to use both global and local geometric cues. Furthermore, all participants regardless of training size, testing size, or the relationship between training size and testing size allocated responses to the geometrically correct locations at above-chance rates in the rectangular testing environment. This shows that participants were able to orient based on global geometric cues (principal axis of space) in the absence of local geometric cues (corner angles). Importantly, training size, testing size, or the relationship between training size and testing size did not influence the use of global geometric cues.

When global and local geometric cues were placed in conflict in the parallelogram-shaped environment, only the relationship between training size and testing size influenced the use of local geometric cues. Neither training size nor testing size alone influenced the reliance on local geometric cues for reorientation. Thus, it appears that the influence of local geometric cues results from the type of change that occurs in the environment size from training to testing. Local cues exert more influence when environment size decreases from training to testing.

Previous literature suggests that training size has at least some effect in determining cue preference during reorientation (Ratliff & Newcombe, 2008; Sovrano, Bisazza, & Vallortigara, 2005; Sovrano, Bisazza, & Vallortigara, 2007; Vallortigara, Feruglio, & Sovrano, 2005). Our design allowed for us to further explore those findings by isolating effects of training size, testing size, and the relationship between the two. Our results suggest that neither training size nor testing size alone fully accounts for the observed preferences when cue use is placed in conflict.

In other words, training size does account for changes in cue preference during reorientation but only when considered as a function of its relationship to the paired testing size.

Our findings replicated previous research examining the influence of enclosure size on the use of local and global geometric cues (Sturz et al., 2012). Local geometric cues appear to function similarly to feature cues such that local geometric cues seem to exert more influence in large environments than in smaller environments (Miller, 2009). In direct comparison to Sturz et al. (2012), our Larger-to-Smaller group (comprised of both Large-to-Medium and Medium-to-Small groups) performed much the same as their Large Training Group-to-Small Testing Group, in that both groups showed a noticeable preference for local geometric cue use. Our Smaller-to-Larger group (comprised of both Small-to-Medium and Medium-to-Large groups) also performed similarly to their Small Training Group-to-Large Testing Group. This result has implications for the way in which we conceptualize the observed effects of enclosure size on cue reliance. In short, perhaps our existing understanding of enclosure size effects could be understood differently in terms of the relationship between training and testing enclosures rather than an isolated influence of either training or testing enclosures.

Research has yet to establish whether there exists a concrete “large” or “small” environment in perceptual terms. In other words, we do not yet know if there is a generally shared perception of what is considered “large” or “small” either within or across species; one could argue that the perception of environment size exists as a function of the size of the individual organism in comparison to its perceived environment. On the other hand, there is the potential that there is a simpler general understanding of relative environment size within species. Perhaps a clearer effect of training size or testing size or the relationship between training size and testing size could be determined if we better understood the exact features that delineate an objective perceptual size difference. Sturz, Boyer, Magnotti, and Bodily (in press) have made important progress toward discovering a more objective understanding of enclosure size differences. Their recent study combined eye-tracking software with behavioral measures to determine an objective threshold for geometric shape discrepancy between 2D rectangles and squares. Their results suggest that participants base shape decisions on the major and minor axes of space (i.e., the principal axes of space). More specifically, their results established an objective baseline for determining the difference between a rectangle and a square. This finding could potentially be adapted to help develop a more objective measure of environment size perception. Their data also suggest that initial shape decisions appear to be made based on the full geometric perception of the shape, rather than a featural comparison. In other words, shape decisions appear to be influenced more by geometry than features, and more specifically, global geometry more than local geometry.

Considering our results suggest that the relationship between enclosure size from training to test is the motivating factor in determining local geometric cue preference, perhaps we need to reconsider how to best categorize enclosure size effects moving forward. Perhaps we need to view enclosure size effects as a function of the training-testing enclosure relationship, since determining an objective absolute perception of small, medium, and large enclosure sizes remains a difficult task for now. On the other hand, future research could also strive to establish perceptual thresholds at both the individual and species level in an effort to normalize an objective understanding of enclosure size thresholds. Regardless, once a more objective understanding of the perceptual differences between sizes is established, perhaps the present task could be adapted to further elucidate the objective differences between different size comparisons.

References

Bodily, K. D., Eastman, C. K., & Sturz, B. R. (2011). Neither by global nor local cues alone: evidence for a unified orientation process. *Animal Cognition, 14,* 665-674.

Buckley, M. G., Haselgrove, M., & Smith, A. D. (2015). The developmental trajectory of intramaze and extramaze landmark biases in spatial navigation: An unexpected journey. *Developmental Psychology, 51*(6), 771-791.

Buckley, M. G., Smith, A. D., & Haselgrove, M. (2014). Shape shifting: Local landmarks interfere with navigation by, and recognition of, global shape. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(2), 492-510.

Cheng, K. (1986). A purely geometric module in the rat's spatial representation. *Cognition, 23*(2), 149-178.

Cheng, K. (2008). Whither geometry? Troubles of the geometric module. *Trends in Cognitive Sciences, 12*(9), 355-361.

Cheng, K. & Newcombe, N. S. (2005). Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychonomic Bulletin & Review, 12* (1), 1-23.

Chiandetti, C. & Vallortigara, G. (2008). Spatial reorientation in large and small enclosures: Comparative and developmental perspectives. *Cognitive Processing, 9,* 229-238.

Daugherty, A. M. & Raz, N. (2017). A virtual water maze revisited: Two-year changes in navigation performance and their neural correlates in healthy adults. *Neuroimage, 146*, 492-506.

de Castell, S., Jenson, J., & Larios, H. (2015). Gaming experience and spatial learning in a virtual Morris Water Maze. *Journal of Virtual Worlds Research, 8*(1), 1-18.

Harvey, D. R., Brant, L., & Commins, S. (2009). Differences in cue-dependent spatial navigation may be revealed by in-depth swimming analysis. *Behavioural Processes, 82*, 190-197.

Higa, K. K., Young, J. W., & Gayer, M. A. (2016). Wet or dry: translatable “water mazes” for mice and humans. *The Journal of Clinical Investigation, 16*(2), 477-479.

Kelly, D. M., Chiandetti, C., & Vallortigara, G. (2011). Re-orienting in space: do animals use global or local geometry strategies?. *Biology Letters*, *7*(3), 372-375.

Kelly, D. M., Durocher, S., Chiandetti, C., & Vallortigara, G. (2011). A misunderstanding of principal and medial axes? Reply to Sturz & Bodily. *Biology Letters*, *7*(5), 649.

Learmonth, A. E., Newcombe, N. S., Sheridan, N., & Jones, M. (2008). Why size counts: Children’s spatial reorientation in large and small enclosures. *Developmental Science, 11*(3), 414-426.

Learmonth, A. E., Nadel, N., & Newcombe, N. S. (2002). Children’s use of landmarks: Implications for modularity theory. *Psychological Science, 13*(4), 337-341.

Miller, N. (2009). Modeling the effects of enclosure size on geometry learning. *Behavioural Processes, 80,* 306-313.

Morris, R. G. M. (1981). Spatial localization does not require the presence of local cues. *Learning and Motivation*, *12*, 239-260.

Morris, R. G. M. (1984). Developments of a water-maze procedure for studying spatial learning in the rat. *Journal of Neuroscience Methods, 11*, 47-60.

Ratliff, K. R. & Newcombe, N. S. (2008). Reorienting when cues conflict: Evidence for an adaptive-combination view. *Psychological Science, 19*(12), 1301-1307.

Schoenfeld, R., Schiffelholz, T., Beyer, C., Leplow, B., & Foreman, N. (2017). Variants of the Morris water maze task to comparatively assess human and rodent place navigation. *Neurobiology of Learning and Memory, 129*, 117-127.

Sovrano, V. A., Bisazza, A, & Vallortigara, G. (2005). Animals' use of landmarks and metric information to reorient: effects of the size of the experimental space. *Cognition, 97*, 121-133.

Sovrano, V. A., Bisazza, A., & Vallortigara, G. (2007). How fish do geometry in large and in small spaces. *Animal Cognition*, *10*(1), 47-54.

Sovrano, V. A. & Vallortigara, G. (2006). Dissecting the geometric module: A sense linkage for metric and landmark information in animals' spatial reorientation. *Psychological Science, 17*(7), 616-621.

Sneider, J. T., Hamilton, D. A., Cohen-Gilbert, J. E., Crowley, D. J., Rosso, I. M., & Silveri, M. M. Sex differences in spatial navigation and perception in human adolescents and emerging adults. *Behavioural Processes, 111*, 42-50.

Sturz, B. R. (2014). Modeling a role of field of view in the extraction of geometric cues during reorientation. *Frontiers in Psychology, 5*, 535. DOI: 10.3389/fpsyg.2014.00535

Sturz, B. R. & Bodily, K. D. (2011). Is surface-based orientation influenced by a proportional relationship of shape parameters? *Psychonomic Bulletin & Review, 18,* 848-854.

Sturz, B. R., Boyer, T. W., Magnotti, J. F., & Bodily, K. D. (in press). Do eye movements during shape discrimination reveal an underlying geometric structure? *Animal Behavior & Cognition.*

Sturz, B. R., Forloines, M. R., & Bodily, K. D. (2012). Enclosure size and the use of local and global geometric cues for reorientation. *Psychonomic Bulletin & Review, 19*(2), 270-276.

Sturz, B. R., Gurley, T., & Bodily, K. D. (2011). Orientation in trapezoid-shaped enclosures: Implications for theoretical accounts of geometry learning. *Journal of Experimental Psychology: Animal Behavior Processes, 37*(2), 246-253.

Sturz, B. R. & Kelly, D. M. (2009). Encoding of relative enclosure size in a dynamic three-dimensional virtual environment by humans. *Behavioural Processes, 82*, 223-227.

Vallortigara, G, Feruglio, M., & Sovrano, V. A. (2005). Reorientation by geometric and landmark information in environments of different size. *Developmental Science, 8*(5), 393-401.

van Gerven, D. J. H., Ferguson, T., & Skelton, R. W. (2016). Acute stress switches spatial navigation strategy from egocentric to allocentric in a virtual Morris water maze. *Neurobiology of Learning and Memory, 132,* (29-39).