Spring 2014

Stimulus Modality and the Rotational Error: An Examination of the Various Reorientation Accounts in Humans Using a 3D Virtual Environment

Samuel P. Police

STIMULUS MODALITY AND THE ROTATIONAL ERROR: AN EXAMINATION OF THE VARIOUS REORIENTATION ACCOUNTS IN HUMANS USING A 3D VIRTUAL ENVIRONMENT

by

SAMUEL PAUL POLICE

(Under the direction of Kent D. Bodily)

ABSTRACT

Reorientation occurs when an organism enters a novel environment and utilizes cues within said environment to get its bearings. Though reorientation occurs, little is known about which cues are utilized to reorient and the mechanism underlying this reorientation process. Three competing accounts of how the reorientation process occurs were presented and discussed in terms of which cues are predicted to be utilized in reorientation: the geometric module, the associative strength model, and the adaptive-combination view. In the present experiment, human participants were trained in an immersive, 3D virtual environment trapezoid to local a goal location in the presence of either a visual, auditory, or no disambiguating cue. Then, all participants were tested using an immersive, 3D virtual environment in four testing enclosures (trapezoid control, rectangle, right parallelogram, left parallelogram). The present study's results are cautiously interpreted as consistent with the adaptive combination account. Furthermore, regardless of stimulus modality, featural information competed with geometric information.

INDEX WORDS: Spatial Reorientation, Spatial Learning, Virtual Environment, Auditory Cues

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B.S., Georgia Southern University, 2012

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

2014

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Electronic Version Approved:

May 2014

DEDICATION

I would like to dedicate this book to my family, friends, and everyone in the department who has helped shape my academic and professional growth over the past two years. Words cannot express my gratitude for your contributions and encouragement; I would not be where I am today without you.

ACKNOWLEDGEMENTS

I would first like to acknowledge and thank Dr. Kent Bodily for guidance, support, and opportunities throughout the course of my academic career. Having Dr. Bodily as a mentor has led me to greater accomplishments than I would have imagined. Thank you for the challenges that I have overcome as well as the opportunities to become more involved in my undergraduate academic career as well as continuing to provide opportunities throughout my graduate career. You've always seen the work ethic and drive in me that has led to the academic and personal growth that I am proud of today. I would also like to thank Dr. Bradley Sturz. The research and teaching opportunities that you have provided in your lab and courses has led me through a brief foray into evolutionary theory as well as allowing me to find my passion for teaching as well as hone my skills. Last but certainly not least, I would like to thank Dr. Janice Steirn. I've learned an extraordinary amount in your classes throughout my career, including the skillsets that I employ in teaching, but you also took the chance to help plan for my undergraduate capstone project if I studied abroad in Germany. From those discussions, I still plan to tour the birth places of psychology throughout Germany one day. Again, words cannot express my gratitude for everything. This book would not have come into fruition without each of you pushing me to become the better version of myself.

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CHAPTER 1

INTRODUCTION

The mechanism underlying spatial reorientation has been debated over the past few decades. Originally, Cheng (1986) discovered that when trained to find a goal location in a rectangular enclosure with disambiguating beacons, rats approached the goal location and its rotational equivalent (i.e., the opposite location) when tested without beacons. This phenomenon has been reproduced in various animals including chicks, pigeons, fish, rhesus monkeys, children, and adult humans (see Cheng et al., 2013; Cheng & Newcombe, 2005 for review). These findings are of particular interest due to the fact that these organisms did not solely utilize the landmarks within the environment to differentiate the goal location and its rotational equivalent. Thus, it has been suggested that organisms encode more information about the enclosure other than landmarks despite not needing this information about the environment to reorient.

Purpose of the Study

Past research has found evidence supporting three accounts to explain the mechanism(s) behind how reorientation occurs (Cheng, 1986; Cheng, Huttenlocher, & Newcombe, 2013; Miller & Shettleworth, 2008; Ratliff & Newcombe, 2008). Given the nature of the three accounts outlined below, it can be difficult to derive distinct predictions from each account; therefore, it was imperative to develop a novel method of testing to dissociate these accounts (Bodily, Eastman, & Sturz, 2011; Bodily et al., 2013). The current research aimed to add to the literature by examining reorientation with a paradigm that allows for three distinct predictions from the different accounts of the mechanism(s) underlying reorientation. The paper begins with an overview of the different types of cues that organisms can use in an environment to reorient followed by discussion of the accounts that have been proposed to explain the use of these cues.

CHAPTER 2

REVIEW OF PAST LITERATURE ON REORIENTATION

Within any given environment, there are two primary types of cues that organisms can utilize to reorient and navigate through that environment: featural and geometric (Bodily, Eastman, & Sturz, 2011). Featural cues are objects within the environment such as beacons or landmarks (Bodily et al.). These features of the environment provide both direction and distance cues about the goal location within the environment (Bodily et al.). Alternatively, geometric cues consist of wall lengths, corner angles, and the axes of space (Bodily, Eastman, & Sturz, 2011). These geometric cues were further divided into local (e.g., wall lengths, corner angles) and global (e.g., principal axes) geometric cues. As defined by Bodily et al., the major principal axis passes through centroid of space so that the enclosure is evenly distributed around the axis (see Fig. 1).

As previously stated, numerous types of animals, including humans, appeared to utilize these geometric cues to reorient themselves to the environment. Though there is ample evidence regarding animals orienting within a novel environment, competing accounts have been developed in an attempt to understand the mechanism underlying the reorientation process. These accounts outline predictions as to which cues are utilized to reorient and are discussed in detail below.

Geometric Cues

Geometric cues were introduced as a possible explanation of how animals orient in a novel enclosure (Cheng, 1986). Cheng proposed that rats and other animals might reorient using a geometric module. This geometric module account suggests that organisms perceive and encode these global geometric cues separate from other spatial information.

Fodor (1983) first discussed the notion of the mind being modular (i.e., domain specific, hardwired, and autonomous parts of the mind that function independently of other modules). Cheng (1986) applied this notion of modularity to suggest that the geometric cues within the environment are encoded separately from the featural cues, thus eliminating any sort of inter-cue competition. Though this account allows for the encoding of both types of environmental cues, the main distinction is that neither influences the other.

Sturz and Kelly (2009) found evidence of the rotational error phenomenon within humans by utilizing a three-dimensional virtual environment during training and testing. Sturz and Kelly trained humans in a rectangular enclosure with four distinct landmarks (one in either corner) and removed the distinguishing feature of the landmarks during testing. Their methodology produced findings consistent with Cheng (1986) with regard to participants making the rotational error suggesting that this phenomenon occurs within humans and may be produced utilizing a virtual environment.

Similarly, Sturz, Gurley, and Bodily (2011) examined what components of geometric information were utilized to reorient within a novel enclosure as well as developed a novel way to parse out local and global geometric cues. Different types of global geometric information has been suggested in the past (e.g., principle axes, medial axes); however, the scope of the current study was not to delineate which global geometric information was utilized, thus global geometric cues will be discussed as such (Kelly et al., 2011; Sutton, 2009). Sturz et al. trained undergraduate students to approach a distinctively marked goal location (utilizing visual featural cues) within a rectangular enclosure (see also Cheng, 1986; Kelly, Chiandetti, & Vallortigara, 2010). Sturz et al. trained participants to approach a corner in a rectangular enclosure, then tested participants in trapezoid-shaped enclosures in a dynamic virtual environment. By utilizing trapezoidal enclosures as a means to test participants' reorientation strategy, this allowed for the juxtaposition of local versus global geometric cues by disambiguating the local geometric cues (wall lengths, corner angles) in the trained corner and the rotational equivalent. Furthermore, they found evidence, similar to that discussed by Cheng and Newcombe (2005), which the rotational error phenomenon occurs within a virtual environment, thus supporting the notion of the geometric account. This finding led Sturz et al. to conclude that organisms rely on the global geometric cues (i.e., principal axis) to reorient within a novel environment when global and local geometric cues conflict.

In lieu of their recent findings, Sturz and Bodily (2011) examined the extent to which global geometric cues influenced reorientation. The researchers manipulated the ratio of the major principal axis to the minor principal axis (i.e., the axis that is perpendicular to the major principal axis, see Fig. 1). It was predicted that the larger the ratio between the major- and minor-principal axes, the more discriminable the major principal axis would become, thus allowing for organisms to more readily utilize the major principal axis within a reorientation paradigm. Undergraduate students were trained to approach a goal location within a virtual environment (similarly to Sturz, Gurley, and Bodily, 2011). During training, participants were trained within a concave hexagon (i.e., hour-glass shaped hexagon, larger discriminable ratio) or a convex hexagon (i.e., honey-comb like hexagon, smaller discriminable ration) with no landmarks present within the environment. The concave hexagon had the larger principal axis discriminability ratio. Following training, participants were tested in a control enclosure (which was identical in dimensions to the enclosure participants were trained in) as well as three novel enclosures (rectangle and two parallelograms).

Sturz and Bodily (2011) found that participants that were trained with the higher discriminability ratio responded more to principal axis predicted locations in testing compared to participants who received training with the lower discriminability ratio. This result was consistent across all test enclosures and was suggestive that the larger ratio allows for more reliable utilization of the principal axis within an environment. Though participants who were trained with the larger discriminability ratio outperformed those trained with the smaller discriminability ratio, it is worth noting that smaller discriminability ratio group did perform better than chance during testing. This is important because even when the discriminability ratio is relatively small (0.25), participants still utilized the principal axis during testing.

Previous research has suggested that the geometric module account is accurate regarding how organisms (e.g., rats, birds, humans) reorient within a given environment (Bodily, Eastman, & Sturz, 2011; Cheng, 1986; Cheng & Newcombe, 2005; Kelly, Chiandetti, & Vallortigara, 2010; Sturz & Bodily, 2011; Sturz, Gurley, & Bodily, 2011). Though the geometric module account has been supported throughout the literature; different findings suggest that the account is lacking with regard to reorientation (Miller & Shettleworth, 2007, 2008; Ratliff & Newcombe, 2008). One shortcoming of the geometric module account pertains to cue competition. As with the geometric module account, being modular by nature leaves no room for influence of other environmental cues (e.g., local geometry, featural cues). Furthermore, Miller and Shettleworth (2007, 2008) found evidence suggesting that this cue competition can and has occurred within a reorientation paradigm, thus arguing that the geometric module account was ineffective in describing the mechanisms underlying reorientation. In lieu of these findings, two other accounts have developed with regards to how organisms reorient within the environment.

Featural Cues

Miller and Shettleworth (2007) proposed an account derived from the Rescorla-Wagner Model, in which featural (e.g., beacons and landmarks) and local geometric cues (e.g., wall lengths and corner angles) compete within the environment. This account predicts that the cue(s) that have the most associative strength compared to the other cues within an environment are the cues with which organisms reorient. Miller and Shettleworth applied their adaptation of the Rescorla-Wagner Model to spatial reorientation, in particular, examining Cheng's (1986) geometric module account.

Furthermore, Miller and Shettleworth (2007) examined how learning of geometric information impacted the learning of other spatial cues. They argued that if there was no evidence of overshadowing between visual featural cues and geometric cues within the reorientation paradigm, then it would seem supportive of the geometric module account; however, if overshadowing occurred, then it would be supportive of an alternative explanation to the geometric module account. As defined by Miller and Shettleworth, overshadowing occurs when training with two, redundant cues (i.e., predicting the same outcome), less is learned about one cue compared to the other.

Previous research suggests that overshadowing occurs within the spatial domain in a variety of spatial reorientation tasks (both utilizing physical environments and virtual environments) and across a wide variety of species (Alexander, Wilson, & Wilson, 2009; Cheng, 2008; Miller & Shettleworth, 2007; Pearce et al., 2006). As previously postulated by Miller and Shettleworth, evidence of these phenomena (e.g., overshadowing) are suggestive that another explanation may be better suited to account for how reorientation regarding geometric and featural components occur.

Furthermore, the associative strength account allows for cue competition between local geometric and featural cues (Miller & Shettleworth, 2007, 2008). In addition, the associative strength account allows for distinct predictions regarding which cues will be utilized to reorient within a given environment depending on which has the most associative strength. Given the attributes of the associative strength account, it is important to note that one shortcoming of this account is a disregard for any global geometric cues.

Geometric and Featural Cues

Cheng and Newcombe (2005) composed a review of the literature regarding the rotational error within spatial reorientation. Their review encompassed studies that examined a wide variety of species that have both supported and cast doubt on the geometric module account. Their review has led to the development of another alternative explanation for how organisms reorient within the environment: the adaptive-combination account.

Ratliff and Newcombe (2008) proposed the adaptive combination account of how organisms reorient within an environment. This account suggests that both geometric and featural cues are encoded, and the cue(s) that are the most salient, reliable, have the most relative strength, and the most previous experience, are the cues that are utilized to reorient. Similarly to experiments that have led to the previously discussed accounts, the human experiments that led to the development of the adaptive combination account all have utilized visual featural cues.

Though Miller and Shettleworth's (2007) associative strength account makes similar predictions of responses/behaviors as the adaptive-combination account, the mechanism that drives the behaviors/responses are different between these accounts. The adaptive combination account suggests the organism will utilize all relevant cues in order of importance (as determined by saliency, reliability, previous experience, etc.); whereas the associative strength account suggests that the cues have attentional weights as such that the organism will utilize only the cue with the largest associative strength. This exemplifies a major difference between the associative strength account and the adaptive-combination account.

Aforementioned, the adaptive combination account allows for all three types of information within an environment to factor into which type of cue is utilized. This selection/utilization relies upon which cue has the most previous experience, saliency, or reliability associated with it. Furthermore, the adaptive combination account allows for cue competition to occur across different cues (similarly to the associative strength account, with the addition of global geometric information). Though this account is encompassing of the three types of information in an environment, the account has difficulty making distinct predictions of responding within a given environment (see Table 1 for breakdown of account and cues utilized).

Virtual Environments

One methodology that has been utilized extensively over the course of the previous years is testing the reorientation paradigm within virtual environments (Bodily, Eastman, & Sturz, 2011; Bodily et al., 2013; Kelly & Bischof, 2005; Sturz & Bodily, 2011; Sturz, Brown, & Kelly, 2009; & Sturz, Gurley, & Bodily, 2011). Sturz, Kelly, and Brown (2010) found that participants performed spatial learning tasks in a virtual environment similarly to performance in a real-world environment. Utilizing virtual environments allows for the manipulation of a much wider array of environments while maintaining a higher level of experimental control. Furthermore, Sturz, Bodily, and Katz (2006) found evidence that humans performed similarly in a virtual environment to pigeons in a real-world foraging task. Also, Sturz, Bodily, Katz, and Kelly (2009) conducted a follow-up experiment where participants completed an open-field search task in both real-world and in a dynamic virtual environment. There were no differences across testing environment, thus adding to the literature suggesting that virtual environment apparatuses have good external validity and the processes underlying spatial learning in virtual environments mirrors the processes utilized in real-world environments.

In addition to the aforementioned literature, Sturz and Kelly (2009) found human participants make rotation al errors within a training and testing paradigm similar to Cheng (1986) that was adapted to a virtual environment apparatus. This findings gave more validity to the utilization of a virtual environment apparatus to test reorientation within human participants.

Current Experiment

As previously mentioned, numerous studies have utilized visual beacons during training across species in a reorientation paradigm. Though non-human animal research has utilized various modalities of featural cues, very little human research has utilized different featural cues other than visual cues (see Cheng & Newcombe, 2005). A cue modality of particular interest is auditory featural cues. Walker and Lindsay (2003) found that participants were able to localize and orient to auditory stimuli. Through examination of previous literature, utilizing a visual featural cue in an environment may occlude other visual cues (i.e., local geometric cues) within an environment (Bodily, Eastman, & Sturz, 2011; Miller & Shettleworth, 2007; Sturz, Gurley, & Bodily, 2011). The present study aimed to circumvent this potential confound by utilizing an auditory beacon to minimize any visual occlusion of local geometric information by featural cue.

In keeping with previous research regarding reorientation by geometry, we utilized virtual environments to determine whether the stimulus modality of the disambiguating featural cue influences reorientation. In order to examine whether this phenomena occurs across modalities, we have performed a partial replication with extension of Bodily, Eastman, and Sturz (2011). We utilized a methodology that has found evidence of this rotational error when participants are trained with visual featural cues. Furthermore, having utilized their methodology, we were able to add to the literature regarding what type of geometric information (i.e., local or global) is utilized regarding reorientation.

Bodily, Eastman, and Sturz (2011) developed a novel design to parse out the local and global geometric cues (see below). The researchers accomplished this by utilizing a trapezoidal enclosure during training in order to isolate local geometric information from global geometric information. Trapezoids isolate these two geometric cues by varying local geometry for the rotational equivalent corner, while holding the global geometric cues constant. If responding occurs to the rotational equivalent corner, then one can conclude that the global geometric cues are being utilized to reorient. In lieu of previous research and pilot studies, the current study's hypothesis was that participants would utilize both local and global geometry to reorient in testing regardless of the beacon type available during training.

Furthermore, we investigated whether there was evidence of cue competition between featural cue modalities and geometric cues. By utilizing the methodology used by Bodily, Eastman, and Sturz (2011), we were able to discriminate between local and global geometric information as well as featural cue modalities. It was expected that all conditions will improve across training and will reach asymptote of responding (see Fig. 3).

Importantly, the current experiment produced unique predictions from each of the three accounts of spatial reorientation. If the geometric account was the mechanism underlying reorientation, one would expect participants to approach the correct and rotationally equivalent corners significantly more than expected by chance across test trials. Furthermore, participants should not perform differently between the test trial types nor featural cue modality (see Fig. 4, panel 1).

If the associative strength account was the mechanism underlying reorientation, one would expect participants to respond to the correct and rotationally equivalent corners significantly more than chance in the left parallelogram test trial, at chance in the control trapezoid and the rectangle test trial, and below chance in the right parallelogram test trial (see Fig. 5, panel 1). Furthermore, participants should respond to the correct and rotationally equivalent corners significantly most in the no beacon condition, then the auditory only condition, and finally in the visual only condition. One would predict these group differences by cue competition that could occur between the featural and geometric cues, thus there would be the least cue competition in the no beacon groups (as there is no feature to compete with local geometric information), followed by the auditory only group as the feature cue is a different stimulus modality (auditory) compared to the geometric cues (visual). One would predict that there would be more cue competition in the visual only group as the feature cue is the same stimulus modality (visual) as the geometric cues.

If the adaptive combination account was the mechanism underlying reorientation, one would expect participants to respond to the correct and rotationally equivalent corners significantly above chance in the control, rectangle, and left parallelogram test trials, and respond at the correct and rotationally equivalent corners at chance in the right parallelogram test trial (see Fig. 6, panel 1). Without knowing the salience of the different featural cue modalities, one is unable to make a prediction regarding the manipulation of featural cues.

Table 1

Illustration of Which Cues are Used to Reorient by Account

	Geometric Module Account	Associative Strength Account	Adaptive Combination Account
Global Geometric Cues	X		X
Local Geometric Cues		X	X
Featural Cues		X	X

Table 1. Illustration of which cues are used to reorient by account.

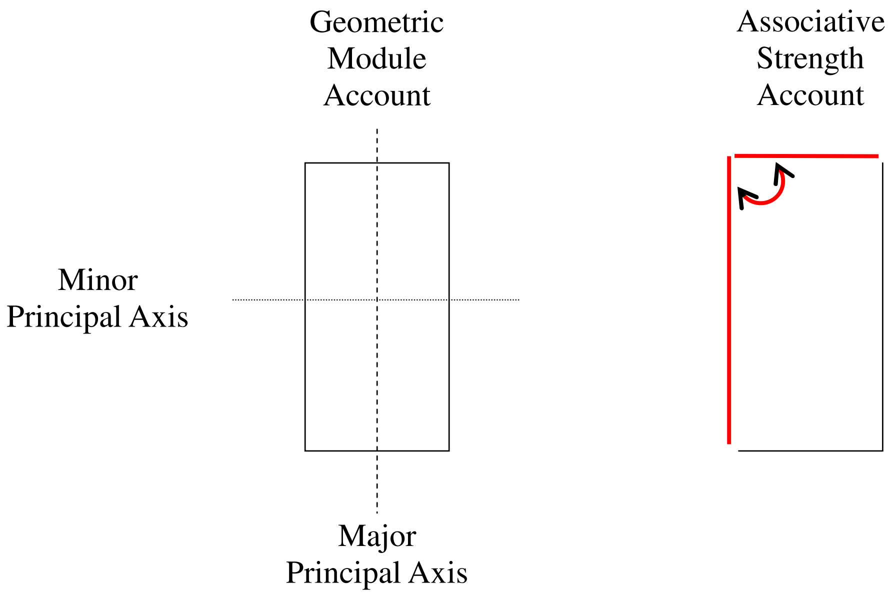

Figure 1. Illustration of cues utilized to reorient by reorientation account. The geometric module account relies on the principal axes within an environment to aid in reorientation. The associative strength account relies on the local geometric cues (wall lengths and corner angles) within an environment to aid in reorientation. The adaptive combination account relies on a combination of the geometric module and the associative strength accounts within an environment to aid in reorientation.

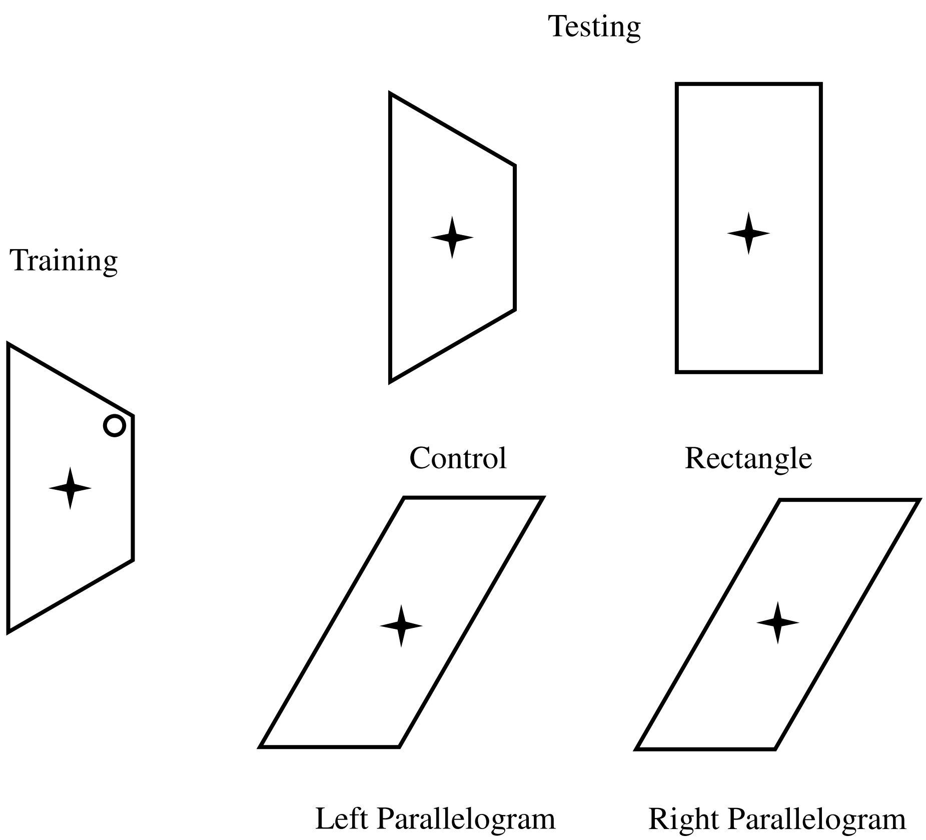

Figure 2. Layout of test enclosures. The training trapezoid and the testing control trapezoid are the same dimensions. Participants begin in the center of each enclosure facing 0°, 90°, 180°, or 270°. The four-point star in the center of the enclosures represents this. The circular object within the training enclosure represents a beacon.

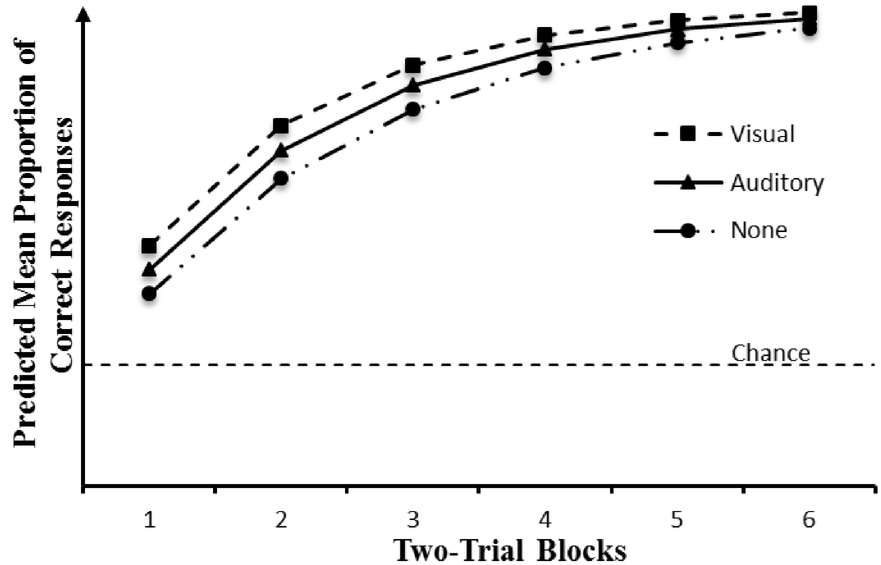

Figure 3. Predicted mean proportion of correct responses during training. Dashed line represents chance (0.25).

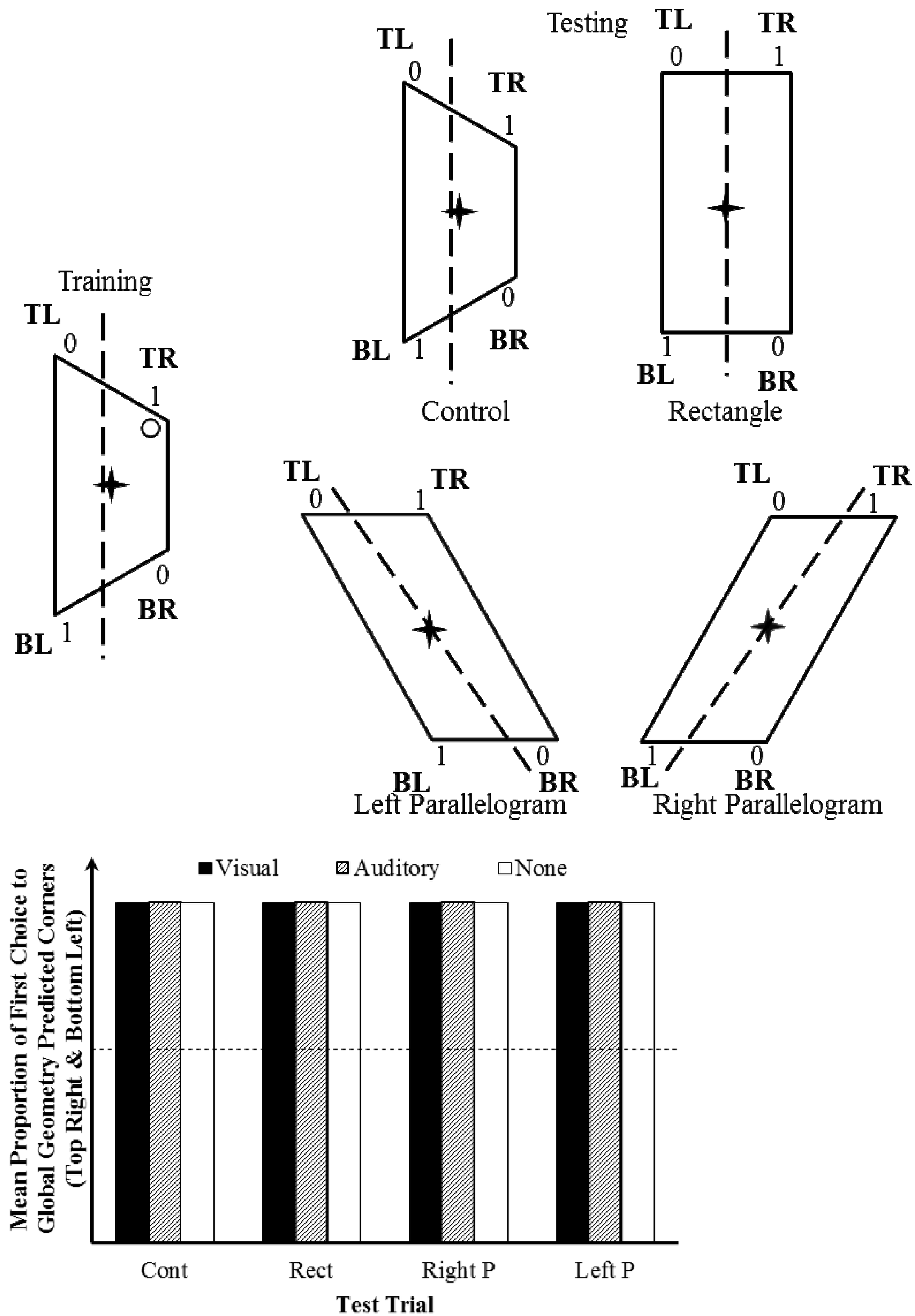

Figure 4. Geometric module account layout of training and testing enclosures and predicted proportion of geometrically correct responses across test trial conditions. *Panel 1:* A breakdown of training and testing enclosure types with the cues utilized to reorient

(e.g., principal axes). The letters outside of the enclosures illustrate the name of the corner (Top Right [TR], Bottom Right [BR], Bottom Left [BL], Top Left [TL]). The numbers outside of the enclosures illustrate the number of congruent cues within the testing environment that were trained during training. *Panel 2:* Predicted performance during testing. Dashed line represents chance. The geometric module account predicts that participants would respond to the correct and rotationally equivalent corners above chance (0.50) in all test trial types due to the principal axis.

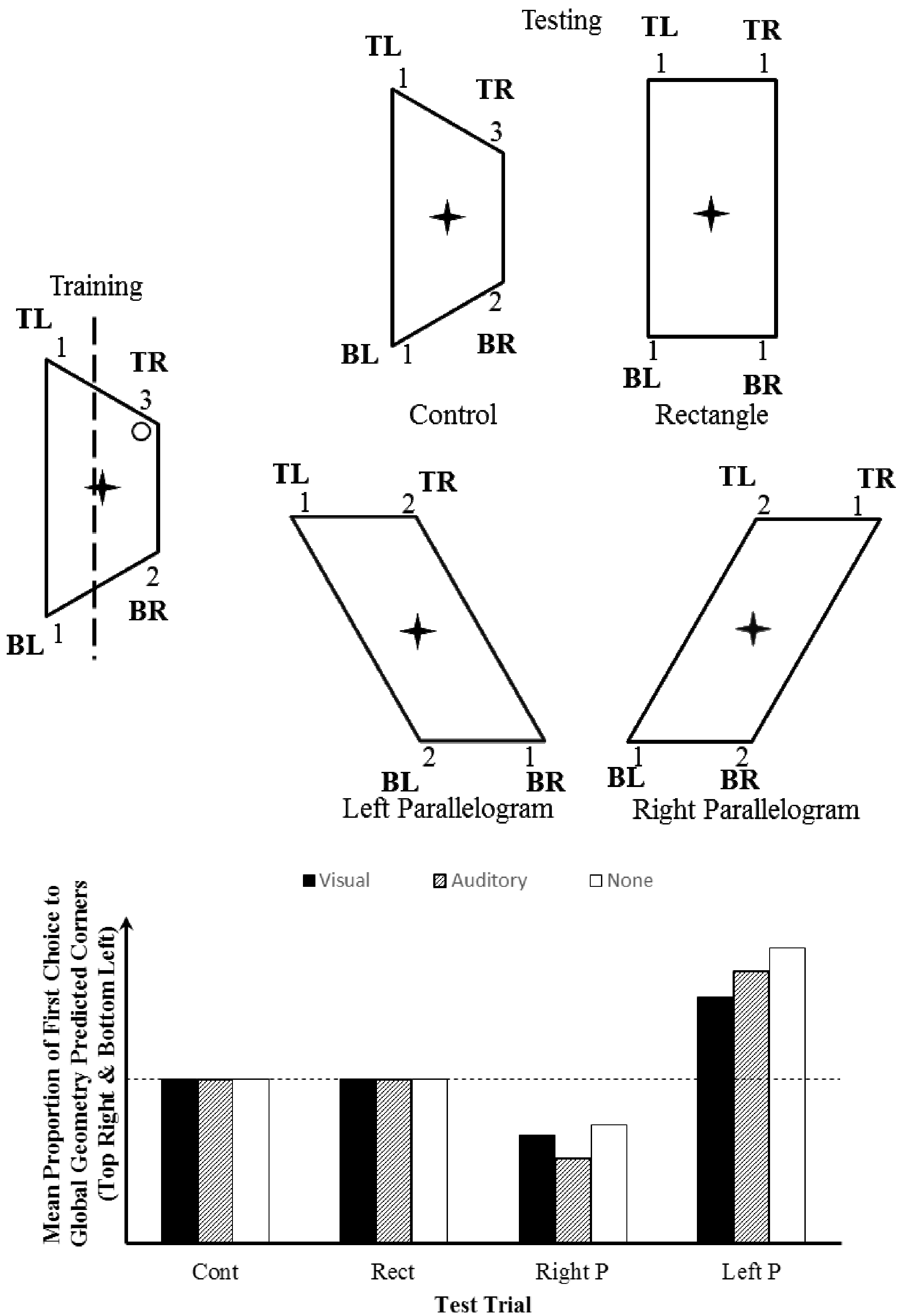
Training
TL
1
TR
3
2
BR
BL
1
Testing
TL
1
TR
3
2
BR
BL
1
Control
TL
TR
1
1
1
1
BL
BR
Rectangle
TL
1
TR
2
2
1
BL
BR
Left Parallelogram
TL
2
TR
1
1
2
BL
BR
Right Parallelogram
Visual
Auditory
None
Mean Proportion of First Choice to Global Geometry Predicted Corners (Top Right & Bottom Left)
Cont
Rect
Right P
Left P
Test Trial

Figure 5. Associative strength account layout of training and testing enclosures and predicted proportion of geometrically correct responses across test trial conditions. *Panel 1:* A breakdown of training and testing enclosure types with the cues utilized to reorient (e.g., wall lengths, corner angles). The letters outside of the enclosures illustrate the name of the corner (Top Right [TR], Bottom Right [BR], Bottom Left [BL], Top Left [TL]). The numbers outside of the enclosures illustrate the number of congruent cues within the testing environment that were trained during training. *Panel 2:* Predicted performance during testing. Dashed line represents chance. The associative strength account predicts that participants would respond to the correct and rotationally equivalent corners above chance (0.50) in the left parallelogram test enclosure. The associative strength account also predicts that participants would respond to the correct and rotationally equivalent corners at chance in the control trapezoid and the rectangle and below chance in the right parallelogram testing enclosures. Furthermore, the associative strength account predicts that one would see the most control by geometry (i.e., responding to the correct and rotationally equivalent corners) in reorientation by the no beacon group, then the auditory beacon group (i.e., less cue competition between auditory features and local geometry), and finally the visual beacon group.

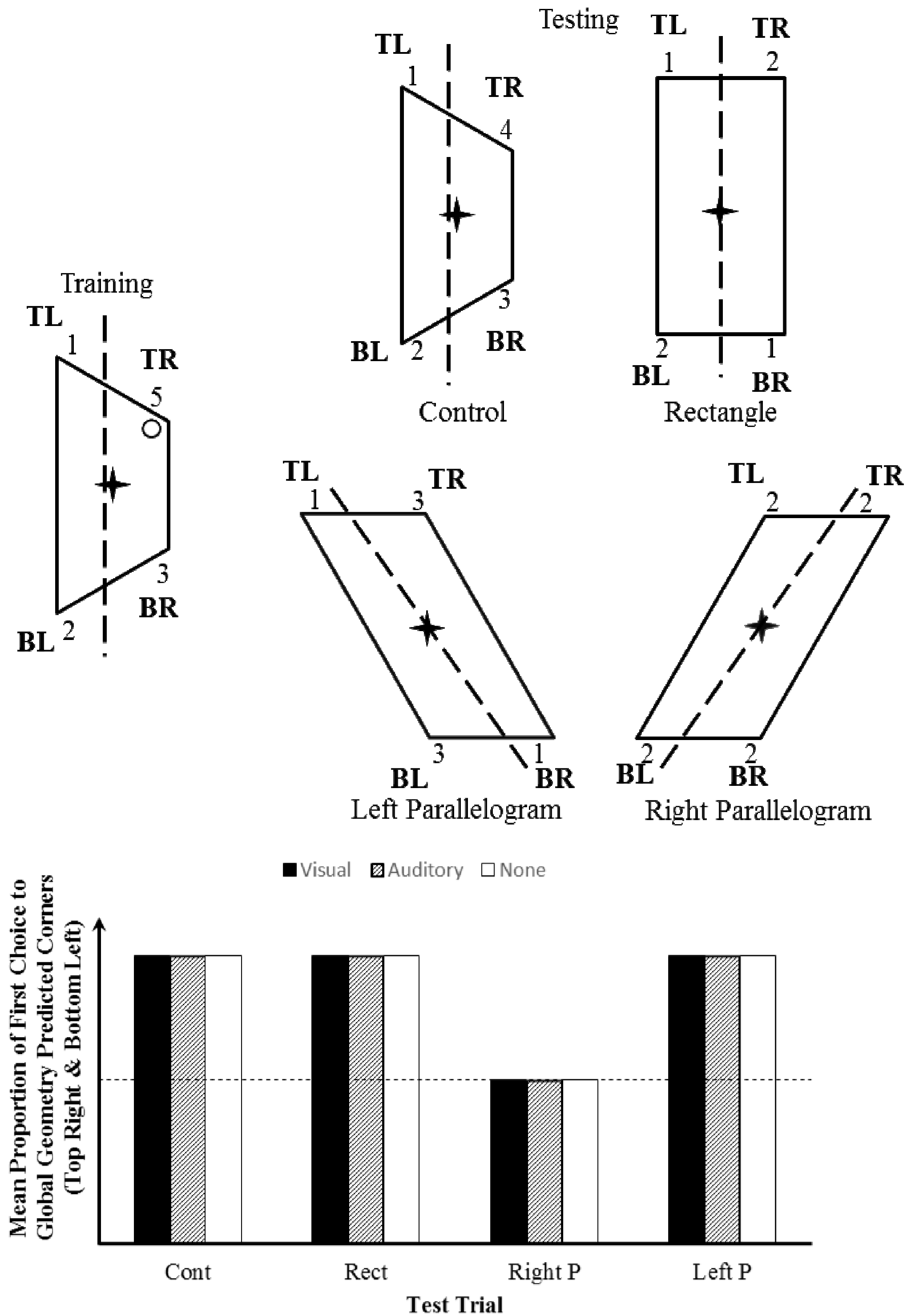

Figure 6. Adaptive combination account layout of training and testing enclosures and predicted proportion of geometrically correct responses across test trial conditions. *Panel*

1: A breakdown of training and testing enclosure types with the cues utilized to reorient (e.g., principal axes, wall lengths, corner angles). The letters outside of the enclosures illustrate the name of the corner (Top Right [TR], Bottom Right [BR], Bottom Left [BL], Top Left [TL]). The numbers outside of the enclosures illustrate the number of congruent cues within the testing environment that were trained during training. *Panel 2:* Predicted performance during testing. Dashed line represents chance. The adaptive combination account predicts that participants would respond to the correct and rotationally equivalent corners above chance (0.50) in the control trapezoid, the rectangle, and the left parallelogram test enclosures. Furthermore, the adaptive combination account predicts that participants would respond to the correct and rotationally equivalent corners at chance in the right parallelogram test enclosure. Without knowing the saliency of each featural cue, it is impossible to make a prediction regarding the stimulus modality if the adaptive combination account best describes the underlying mechanism of reorientation.

CHAPTER 3

METHOD

Participants

Twenty-seven undergraduate students (16 male, 11 female) completed the present study. Participants were randomly assigned between the Visual beacon (8), Auditory beacon (10), and No beacon (9) groups. Participants were recruited through the university's SONA System and received extra class credit as compensation for participation.

Apparatus

A dynamic 3D virtual environment was constructed and rendered using Valve Hammer Editor and ran on the Half-Life Team Fortress Classic game software. A personal computer, three 21-inch flat screen liquid crystal display (LCD) monitors, speakers, and gamepad joystick was utilized as the interface with which the participants interacted within the virtual environment (see Fig. 7). The monitors (3072 x 768 pixels) provided a first-person perspective within the environment (see Fig. 8). Desktop computer speakers served to present the auditory stimuli as well as give auditory feedback during training trials.

Stimuli

Within a virtual environment, enclosure dimensions are measured in virtual units (vu). One vu is roughly equivalent to one inch. We created five virtual enclosures (see Fig. 2): Trapezoid (550 x 275 x 260 vu), Control Trapezoid (550 x 275 x 260 vu), Rectangle (550 x 275 x 260 vu), Right Parallelogram (550 x 275 x 260 vu), and Left Parallelogram (550 x 275 x 260 vu). The two trapezoid enclosures had acute corner angles of 60° and obtuse corner angles of 120°. The two parallelogram enclosures also had acute corner angles of 60° and obtuse corner angles of 120°. Within the rectangle enclosure, all angles measured 90°.

The visual beacon was a colored semitransparent sphere that measured (48 x 48 x 48 vu), one in the trained corner of the enclosures (see procedure).The sphere was colored white. The auditory beacon was pink noise played on loop within the environment in 2s loops of 1s on/1s off at 75db. The auditory beacon was presented with stereo desktop speakers in order for participants to utilize directional information. Walker and Lindsay (2003) found that human participants were able to best locate a burst of noise compared to other auditory stimuli (sonar ping and sine wave). In an effort to make the stimuli more comparable, the visual beacon was visible on a 1s on/1s off loop. In utilizing one feature in each condition, the present study was designed to maximize cue competition. In the no beacon condition, the environments were the same as the visual and auditory beacon conditions, sans beacon.

Procedure

Participants were randomly assigned to one of three groups and instructed to use the gamepad joystick to move throughout the experiment: ↑ (forward), ↓ (backward), ← (rotating left), and → (rotating right). Participants then selected the goal location as marked by either the visual, auditory, or no beacon. If participants navigated to a location that is not denoted by the beacon, they received no feedback until a response to the correct location is made. Participants were only instructed to complete the task to the best of their ability, that their task is the find the correct corner within the enclosures, and that the amount of time the task takes depends on their performance.

Training. Training consisted of 12 trials. Participants began each trial in the center of the enclosure facing in one of four randomly selected directions (e.g., 0°, 90°, 180°, 270°). Participants in the Visual (visual beacon training) group had only one visual beacon available within the training environment. Only the "correct" corner in the training environment was marked with a distinct sphere (white). Participants in the Auditory (auditory beacon training) group served as a direct comparison between visual and auditory beacon training. Participants in the Auditory group had only one auditory beacon available within the training environment. Only the "correct" corner in the training environment was marked with a distinct sound burst (pink noise). Participants in the None (no beacon training) condition were trained in the same manner as the previously discussed conditions sans a disambiguating beacon. This group served as a control group with which to compare performance of both visual and auditory beacon conditions. If a participant entered an incorrect corner, they received no feedback and continued searching until they found the correct corner. Upon entering the correct corner, participants received a positive auditory feedback in addition to a white screen flash for approximately 1s. This served as both auditory and visual feedback so as to not bias participants regarding auditory or visual preference. After this feedback, participants waited during a 7s ITI dark screen and then progressed to the next trial. A criterion for training was determined at the beginning of the experiment that each participant must get at least one of the final four (1/4) training trials (i.e., this means that participants must perform at chance) correct to have their test data included in the analysis.

Testing. Testing consisted of 12 five-trial blocks. Each trial block contained four training and one test trial. The order of training and test trials were randomized within each block. There were four different types of test enclosures presented during testing: Control, Rectangle, Right Parallelogram, and Left Parallelogram (see Fig. 2). Each enclosure was presented a total of three times (equaling a total of 12 test trial blocks). These test enclosures contained no feature (beacon). After making a response, participants received no feedback whether the response was correct/incorrect and then waited for a 7s ITI.

Figure 7. Photo of testing apparatus. The participant sits in the chair facing the middle screen.

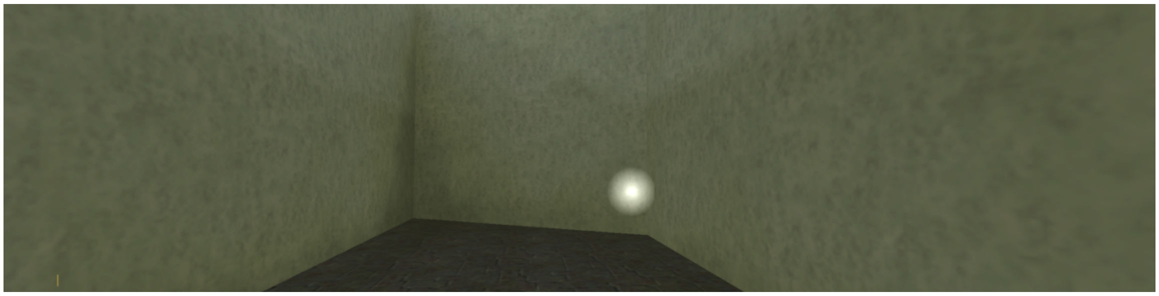

Figure 8. Screenshot from within the virtual environment.

CHAPTER 4

RESULTS

Training

During the present experiment, recruitment was an issue resulting in a total of 27 participants completing the present study. Of the total, four participants (3 male, 1 female) were excluded from data analysis due to not reaching criterion at the end of training (i.e., the participants did not make a correct first response in any of the last four training trials). Gender differences were not analyzed due to lacking sufficient statistical power with a lower sample size. Of the remaining 23 participants (8 in Visual, 8 in Auditory, 7 in None), acquisition was measured as coding the first location participants visited (i.e., first choice) in each trial as either correct (the trained corner with beacon) or incorrect (the other three corners). After coding participant responses, the proportion of correct first choice was computed in two-trial blocks. A 3 x 6 (Beacon x Block), mixed analysis of variance (ANOVA) on acquisition performance with Beacon (visual, auditory, none) and Block (1-6) as factors revealed main effects of Beacon, $F(2, 20) = 352.42$, $p < 0.05$, and Block, $F(5, 100) = 3.63$, $p < 0.05$ (see Fig. 9). There was no significant interaction between Block and Beacon ($p > 0.05$).

The main effect of Beacon was further analyzed using Tukey's LSD ($p < 0.05$). Participants in the Visual condition ($M = 0.96$, $SEM = 0.05$) performed better than both the Auditory condition ($M = 0.40$, $SEM = 0.05$) and the None condition ($M = 0.41$, $SEM = 0.06$), $p < 0.05$ (see Fig. 9). The Auditory and None conditions did not differ, $p > 0.05$.

Upon further examination, participant performance at the end of the training phase (at the end of block 6) in the None and Auditory conditions appeared to drop toward chance. In an attempt to discern whether learning occurred within the Auditory and None conditions, a 3 x 30 mixed factorial ANOVA with beacon and training block as factors revealed a main effect of beacon, $F(2, 20) = 19.62$, $p < 0.05$. Furthermore, the analysis revealed a main effect of training block, $F(29, 580) = 4.20$, $p < 0.05$. These main effects were qualified by a significant interaction of beacon and training block, $F(58, 580) = 1.96$, $p < 0.05$. These results were suggestive that participants learned the task in all conditions (see Fig. 10).

To summarize, the results indicated that participants improved correct first choice across training. Participants in the Visual condition performed better than both the Auditory and None conditions. Participants in the Auditory condition performed similarly to the None condition and continued to improve across training block.

Testing

Test trials assessed whether responding depended on global and/or local geometric cues. Participant responses during testing were measured by proportion of first choice. Responses that were allocated to the top right and bottom left (as predicted by global geometry) were coded as correct and responses to the top left and bottom right were coded as incorrect.

Trapezoid test enclosure. For each group, the number of responses to each response location (i.e., TL, TR, BL, BR) was analyzed via one-sample *t*-tests to determine which condition differed from chance (0.25) for each corner of the trapezoid test enclosure. This analysis was performed in order to gain insight to where participants' allocation of responding occurred within the trapezoid test enclosure (the same enclosure from training after removal of the beacon). One-sample *t*-tests revealed that responding to the top left (TL) corner in the no beacon condition performed significantly lower than chance, $t(6) = -2.56$, $p < 0.05$. Also noteworthy, responding to the top right (TR) corner in the no beacon condition trended toward being significantly above chance, $t(6) = 2.22$, $p < 0.07$ (see Fig. 9, panel 2). All other comparisons were not significant nor trending toward significance, $p > 0.07$.

All test enclosures. A 3 x 4 (Beacon x Test Type) mixed ANOVA revealed a trend toward a main effect of test type, $F(3, 60) = 2.24$, $p = 0.09$. There was no main effect of beacon on performance, $F(2, 20)$, = 0.65, $p = 0.53$. Furthermore, there was no significant interaction, $F(6, 60) = 0.17$, $p = 0.99$.

Planned comparison *t*-tests were conducted to determine which conditions were different from chance in each test enclosure. The None condition trended toward significance in the trapezoid test enclosure and chance, $t(6) = 1.62$, $p = 0.16$, as well as in the left parallelogram test enclosure, $t(6) = 1.88$, $p = 0.11$ (see Fig. 11; Table 2). All other planned comparisons were not significant nor trending toward being significantly different from chance, $p > 0.20$.

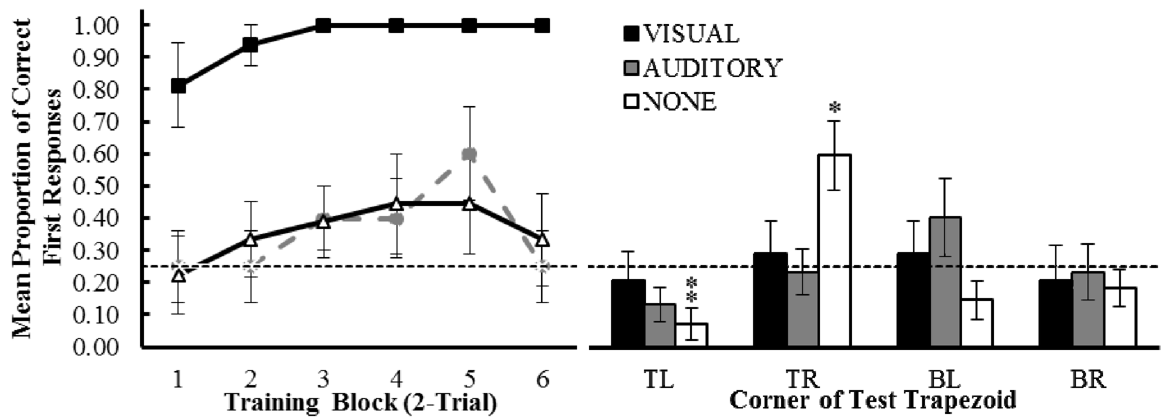

Figure 9. Training acquisition and trapezoid-test response distributions for beacon type (Visual [filled black], Auditory [filled grey], and None [unfilled]) groups. *Left panel* plots mean proportion of correct first responses across training two-trial blocks. *Right panel* plots mean proportion of responses across corners (response locations) of the trapezoid-test enclosure in the absence of the trained beacon. One asterisk denotes trending toward significance ($p < 0.07$); two asterisks denote significance ($p < 0.05$). Dashed lines represent chance performance (0.25). Error bars represent standard error of the means.

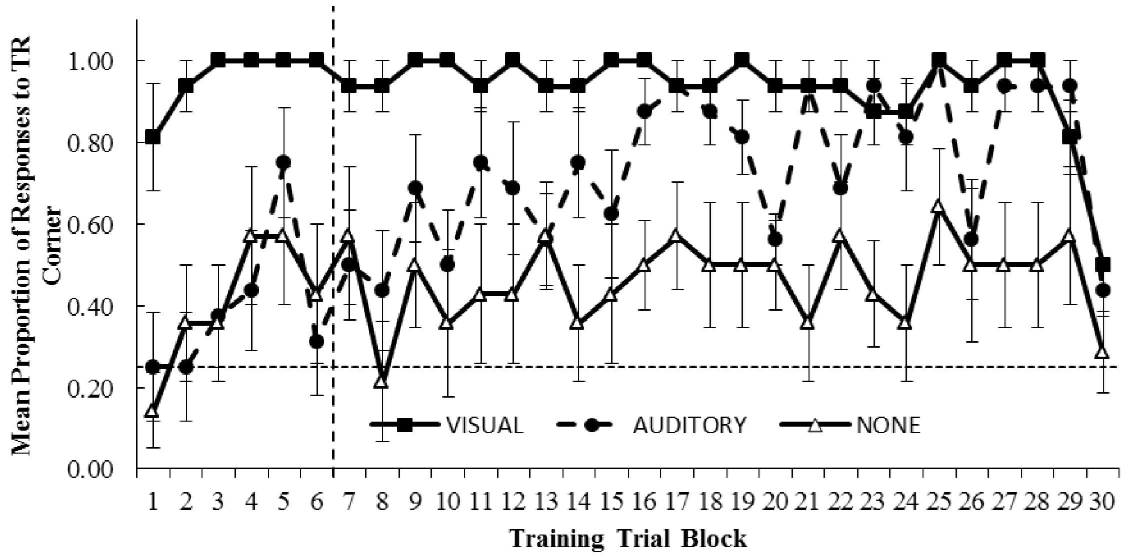

Figure 10. Training acquisition across all training trial blocks (includes training trials within testing phase). The vertical dashed line represents the end of training/beginning of testing phase. The horizontal dashed line represents chance (0.25).

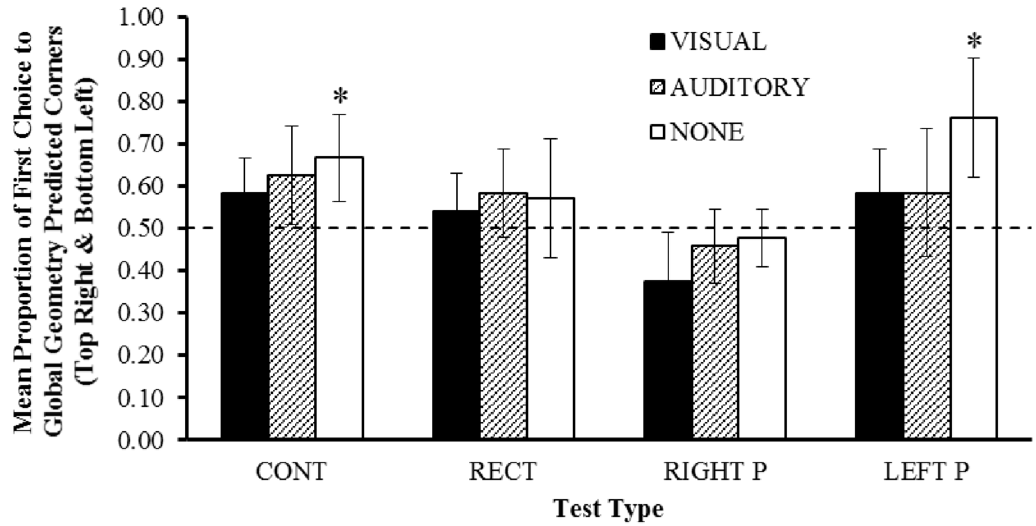

Figure 11. Mean proportion of correct responses in each test enclosure as predicted by global geometry (TR & BL corners). Asterisk (*) denotes groups that trended toward being significantly different from chance, $p < 0.20$. Dashed line represents chance performance (0.50). Error bars represent standard error of the means.

Table 2

Comparison of Predicted Outcomes of Each Account to Data Obtained

		Control	Rectangle	Right Parallelogram	Left Parallelogram
Geometric Module Account					
	All Beacons	Above Chance	Above Chance	Above Chance	Above Chance
Associative Strength Account					
	No Beacon	Equal Chance	Equal Chance	Below Chance	Above Chance
Adaptive Combination Account					
	All Beacons	Above Chance	Above Chance	Equal Chance	Above Chance
Obtained					
	No Beacon	Above Chance	Equal Chance	Equal Chance	Above Chance
	Auditory Beacon	Equal Chance	Equal Chance	Equal Chance	Equal Chance
	Visual Beacon	Equal Chance	Equal Chance	Equal Chance	Equal Chance

note. The above chance obtained values trended toward significance, $p < 0.20$.

CHAPTER 4

DISCUSSION

The geometric module account, associative strength account, and the adaptive combination account all make the assumption that multiple components (global geometry, local geometry, and featural cues) within an environment which human and non-human animals can utilize to reorient. The current experiment aimed to test these accounts in enclosures in which each account made exclusive predictions about where responding would occur. If the current study's sample size was increased and the effect holds, then the conclusions made below would garner more evidence for one account of the mechanism(s) underlying reorientation. During testing, only the no beacon group trended toward being different from chance in the trapezoid and left parallelogram test enclosures. Participant performance in the left parallelogram test enclosure seems to support the notion of utilization of local geometric cues as predicted by the associative strength and the adaptive combination accounts. If there would have been more global geometric control, participant responding should have been all above chance in each test enclosure regardless of beacon condition.

Throughout training, the Visual group performed significantly better than both the Auditory and None conditions, suggesting that visual beacons facilitate learning faster than both auditory beacons and no beacons. At the completion of the training phase in the present study, only the Visual group was significantly above chance; however, it was noted that participants in the Auditory and None group continued to improve across training trials within the testing phase (see Fig. 10). This indicates that all conditions learned the task prior to or shortly after entering testing, which consisted of the trapezoid enclosure sans the beacon and three transfer tests.

Given the present study's data, interpretations were made with extreme caution. This was due in part to various null effects (as outlined above) with effects that only trended toward significance. It was worth noting that given the truncated criterion that participants were required to meet (one correct in last four training trials; chance performance), this implications were made with extreme cautiousness.

In the present study, the None condition's proportion of responses to the top left corner was less than chance and proportion of responses to the top right corner was trending toward being significantly higher than chance. This finding is consistent with the adaptive combination account (discussed in greater detail below).

Test performance of both the Visual and Auditory conditions provide some evidence to suggest that when trained to one beacon within the environment, learning of the feature cue (beacon) overshadows learning of both global and local geometric information. This finding is similar to Ratliffe and Newcombe's (2008) supposition that featural cues may overshadow global and local geometric information. The current experiment's finding, particularly the None condition in the left parallelogram test enclosure, fell in line with the adaptive combination account in that participants responded above chance to the TR and BL corners. Furthermore, when examining participant performance in the trapezoid test enclosure, responding occurred above chance to the TR and BL corners. In further examination of response allocation to the trapezoid test enclosure (see Fig. 9, right panel), responding occurs overwhelmingly to the TR corner compared to the BL corner. This finding appears consistent with the adaptive combination account in such that participants would respond more to the TR than BL within the trapezoid test enclosure. To qualify this effect, participants seemed to respond most to the TR, BR, BL, & TL corners, respectively (see Fig. 9, right panel). Though response allocations were not significantly different from one another, the previous interpretation was suggestive of a possible effect if the present study contained appropriate statistical power.

The current experiment's findings are consistent with Ratliffe and Newcombe's (2008) adaptive combination account of reorientation. Though global geometric cues may have influenced responding, there was no evidence suggesting that these cues were used exclusively, as predicted by the geometric module account (Cheng, 1986; Cheng & Newcombe, 2005; Sturz & Bodily, 2011; Sturz, Gurley, & Bodily, 2011). If the global geometric account best explains the mechanism(s) underlying reorientation, one would have expected to see performance above chance for each test enclosure as well as each beacon condition (see Fig. 4).

Surprisingly, the present study's findings were indicative that different stimuli modalities (visual, auditory) had the same cue competition effect. This was interesting in such that featural cues disrupted learning of geometric features during training (as evidenced by test trial performance being at chance across all test enclosures). This finding was intriguing in such that it was expected that auditory features would produce less competition between geometric information as auditory cues do not visually occlude a portion of the environment. Furthermore, if the associative strength account best explained the given data, then one would suspect that a visual cue may have more associative strength over geometric information as the feature provides both directionality and distance; whereas, the auditory cue provides only directionality information to participants.

Furthermore, upon further examination of obtained data compared to the predicted outcomes of each account, the present study's data are most consistent with the adaptive combination account (see Table 2). The present study's data supported 2/4 predictions made in the geometric module account. In addition to the shortage of support of the geometric module account, evidence of cue competition in both beacon conditions (discussed in greater detail below), was condemning of the geometric module account. Furthermore, the present study's data supported 2/4 predictions made by the associative strength account. Although this account allowed for cue competition, as witnessed in the current study, the adaptive combination account was best supported by the data. This claim can be qualified as the data supporting 3/4 of predictions made by the adaptive combination account while allowing for cue competition to occur.

Though the current experiment's data suggests the adaptive combination account may best explain the mechanism(s) underlying reorientation, there were a few limitations of the current study. The first of which was sample size. Cohen (1992) suggested that when using an analysis of variance design with five groups, a sufficient sample size in order to have sufficient statistical power at $\alpha = 0.05$ is 39 participants. As previously stated, only 23 participants completed the study and met criterion during training. This may be due in part to recruitment issues in the middle of the semester after most students had received the maximum amount of extra credit available through the SONA System. Though this may offer some explanation of the data trending toward significance, it was an issue that can easily be remedied in the future by adding more participants to reach Cohen's (1992) suggested number of participants to have appropriate statistical power.

Previous experiments have found evidence supporting control by global geometry within a reorientation paradigm (Cheng, 2005; Cheng & Newcombe, 2005; Gallistel & Cramer, 1996); however, the present experiment's data are inconsistent with these previous findings. If the geometric module better explained the mechanism(s) underlying reorientation (suggesting that there was greater control by global geometry with regard to reorientation), one would have expected to see all conditions responding above chance in the rectangle test enclosure. One may have come to this conclusion as numerous experiments have utilized this test enclosure and have found evidence supporting this account. Furthermore, by utilizing a rectangular test enclosure, one controls for local geometric cues in the present experiment by allocating an equal number of cues available at each corner (see Fig. 5, panel 1). In the present study's findings, responding occurred at chance in the rectangle test enclosure in all conditions, thus contradicting previous findings regarding the geometric module account and the use of global geometric cues.

Furthermore, the present study's experimental design maximized the likelihood of cue competition by training within an environment with one beacon rather than four. This was consistent with previous literature regarding cue competition and the associative strength account (Miller & Shettleworth, 2008); whereas, previous literature that found control by global geometry typically entailed training in an environment with four features (Bodily, Eastman, & Sturz, 2011; Sturz & Bodily, 2011; Sturz, Gurley, & Bodily, 2011).

A final limitation of the present study was the utilization of the triple display monitor. Previous literature has utilized a single monitor apparatus; however in lieu of recent findings, Sturz, Kilday, and Bodily (2013) found that constraining field of view decreased the use of global geometric cues. By utilizing a triple display with a larger field of view, the researchers aimed to mitigate the possibility of disruption of the use of global geometric cues as may have occurred on a single-monitor display. In retrospect, one could suggest that by utilizing a triple display, the image may have decreased the vertical field of view (i.e., the amount of the ceiling visible) which may have interfered with clearly identifying the corner angle.

Despite these limitations, the current study was one of the first to prove the extent to which the uses of different stimulus modalities for reorientation are consistent with current theoretical accounts of reorientation. Though the current study's results provided some support to the adaptive combination account, cautionary interpretation in addition to further examination is necessary. One such endeavor would have a larger sample size (as suggested by Cohen, 1992) as well as possibly incorporating different stimuli modalities such as texture (Sturz et al., 2013). In doing so, may be fruitful in determining which account best describes the mechanism(s) underlying reorientation. By incorporating other stimuli modalities, one may also determine in what context these reorientation accounts become active.

In summary, participants in the visual beacon condition outperformed both auditory and no beacon conditions during training; however, the no beacon condition allocated responses more to the geometrically correct corners in the trapezoid test enclosure compared to visual and auditory beacon conditions. Furthermore, the no beacon condition was the only condition to perform above chance in any transfer test enclosure, thus lending support to the notion of cue competition as predicted by the adaptive combination account. Though these findings lend evidence that’s trending toward the adaptive combination account; however, further examination is necessary.

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