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DUAL TASK TESTING OF THE ADAPTIVE COMBINATION VIEW IN SPATIAL REORIENTATION

by

DONALD G. SULLENS

(Under the Direction of Kent Bodily)

ABSTRACT

If an organism is trained to approach a location within an enclosure the organism will approach the correct location and its geometrically identical location within the environment upon removal of any features. This phenomenon has been termed spatial reorientation, and further studies on how, and to what, organisms reorient have been conducted in the last several decades. In the reorientation literature, two theories have surfaced to fill the void left by the rejection of the initial reorientation theory, the Geometric Module theory. I attempt to discern if the synonym judgement dual task will hinder reorientation in a similar or different fashion than the standard shadowing tasks used. Participants were assigned to a control or dual task condition, in which both groups performed a reorientation task. While performing the reorientation task, the dual task condition was presented with a series of word pairs in which they indicated if the pair of words were synonymous or not. The test indicates Language as a Bridge theory and The Adaptive Combination View may operate via different mechanisms under Baddley's Working Memory Model. I surmise that the Adaptive Combination View utilizes attentional resources of the phonological loop and visuospatial sketchpad while the Language as a Bridge theory utilizes conscious processing stemming from the concepts of the episodic buffer and central executive.

INDEX WORDS: Spatial reorientation, Spatial cognition, Dual task, Working memory, Linguistics, Incidental learning

DUAL TASK TESTING OF THE ADAPTIVE COMBINATION VIEW IN SPATIAL REORIENTATION

by

DONALD G. SULLENS

B.A., Mercer University, 2011

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial Fulfillment of the Requirements for the Degree

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TABLE OF CONTENTS

Page

CHAPTER

LIST OF FIGURES

Page

Chapter 1

INTRODUCTION

Reorientation Phenomenon

In the seminal work by Cheng (1986) it was found that mobile creatures are able to return to a previously trained geometric location within a given environment on subsequent trials, even if starting with a different heading, regardless of other cues such as a distinct visual and textural feature marking a wall. This phenomenon has been termed spatial reorientation. Interestingly, without distinctive features to aid reorientation, the test subjects made what has become known as a rotational error (Cheng, 1986). This error occurs when a subject orients to a corner geometrically identical to the one originally trained, referred to as the rotational equivalent (see *Figure 1*). Since Cheng's (1986) initial work this phenomenon has been reported in a multitude of mobile species varying across different locomotion modalities (e.g. pigeons - Kelly, Spetch, & Heth, 1998; hummingbirds – Hornsby, Hurly, Hamilton, Pritchard, & Healy, 2014; mountain chickadees - Batty, Bloomfield, Spetch, & Sturdym, 2009; redtail splitfins {fish}, Sovrano et al.,

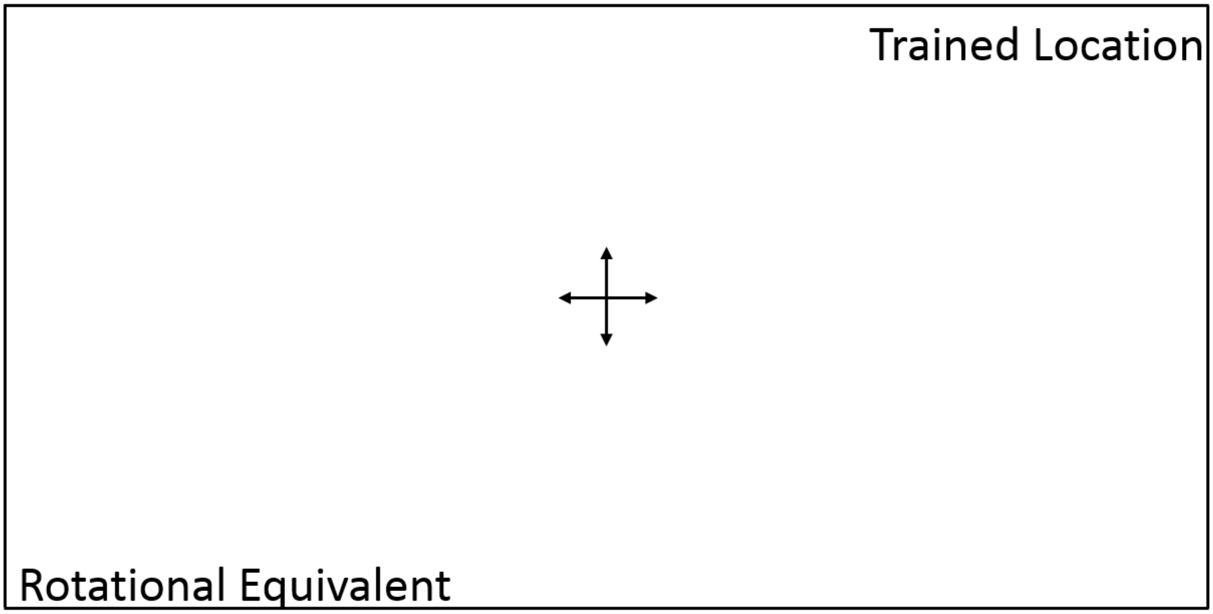

Figure 1. The intersection and direction of the four arrows represents the start location and heading of animals in a reorientation task. The Trained and Rotational Equivalent locations are also labeled. The two remaining corners are also rotational equivalents of each other.

2005;, chicks - Pecchia & Vallortigara, 2012 and Vallortigara, Zanforlin, Pasti, 1990; and humans - Hermer-Vazquez, Moffet, & Munkholm, 2001). Further research in the field has uncovered various orientation cues which these species can use to navigate. Orientation by geometry, for example, is using the shape of the environment to reorient (Cheng, 2005). These geometric cues can either be global or local. Global geometric cues are cues in which the entirety of the environment shape is taken into account such as in principal axis and medial axis accounts of reorientation. (McGregor, Jones, Good, & Pearce, 2006). Both the principal and medial axis accounts utilize mathematically calculated axes based on the shape of the environment. These axes provide directional information for the orienting organism. A local geometric cue on the other hand is when only a specific geometric cue within the environment is used for reorientation, such as a corner angle or wall length (McGregor, et al., 2006). Conversely, featural cues are distinct goal location markers that can vary based on the experiment and subject species being studied (Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2009). Examples of featural cues include wall color (Graham, Good, McGregor, & Pearce, 2006), scent (Cheng, 1986), and distinct goal location color (Sturz & Kelly, 2013). Various models have been posed to account for the reorientation phenomenon and the orientation cues affecting navigation.

CHAPTER 2

BACKGROUND LITERATURE

Geometric Module

Cheng (1986) originally proposed that there was a geometric module for reorientation. In other words there is a specialized mechanism within the brains of mobile creatures that processes and solves navigational tasks quickly and automatically. This specialized cognitive function would correspond with a neurological framework with which reorientation is based on. This module would only be responsible for reorientation, and would not do any other cognitive process. Within Cheng's (1986) original model, features could be mentally placed on a "framework" (mental representation of the area's geometric structure) and used as a subgroup to supplement geometric information. Such geometric information must be held constant in order for the features to be used within the module.

Further research into spatial reorientation has led to the modular view falling out of favor (Cheng, 2008). Cheng (2008) reviewed the literature which indicates problems with the modular view. For example, featural cues, such as wall color, can prevent the usage of geometric cues (Graham et al., 2006). Graham et al. (2006) over three experiments demonstrated that featural cues, such as wall color, can affect reorientation even if no geometric change has occurred. If the modular view was correct, the geometric information should be automatically encoded and therefore available for use, irrelevant of the featural differences. Furthermore, the featural cues should only be used to supplement and add information to the geometric information if needed to complete reorientation. Evidence indicates however that geometric cues are not utilized in isolation which would be predicted from the modularity view (Ratliff & Newcombe, 2007; Graham et al., 2006). In addition to Graham et al.'s (2006) findings, Ratliff and Newcombe (2007; 2008) demonstrated that humans can navigate using geometry during a cue conflict task, but also that exposure to a featural cue during training affects this ability. If reorientation was controlled by a geometric module, featural cues should have no influence over reorientation as they are not geometrically based.

If reorientation was based on a modular process then no other activity should interfere with an organism's ability to navigate to a previously trained location. However, both Hermer-

Vazquez, Spelke, and Katsnelson (1999) and Ratliff and Newcombe (2008) demonstrated that performing a verbal shadowing task while reorienting significantly decreases a human's ability to orient to the goal location correctly. A verbal shadowing task requires the participant to listen to and repeat verbatim audio stimuli presented to him/her as the stimuli is presented. Both Hermer-Vazquez et al. (1999) and Ratliff and Newcombe (2008) utilized a large colored wall along with geometric information and the participants were still unable to reorient based on either stimulus.

When reorientation research utilizes features during training, there are two basic tests to determine whether reorientation is dependent on geometry or features during training. First is the geometry test, in which the previously included feature is no longer in the environment. This test allows the researcher to determine if the participant learned to orient based on the shape of the enclosure. The second test, is the affine test in which the feature is shifted 90 degrees in the environment from its original training position. This shift often places the geometric and feature information in conflict with one another. By examining the response choices of the participants the researchers can determine which orientation cue influenced behavior the most.

Language as a Bridge

One idea proposed to account for how linguistic dual-tasks disrupt human's ability to orientate is referred to as Language as a Bridge (Hermer-Vazquez, Moffet, & Munkholm, 2001). Hermer-Vazquez, Moffet, & Munkholm (2001) concluded human adults convert information into a linguistic format for usable reorientation. This conversion and utilization of other encoded information in a linguistic format allowed human adults to transcend orientation via geometry alone. Hermer and Spelke (1996) conducted a series of experiments manipulating the cues which would accurately predict the location of an objective in a reorientation paradigm. After comparing the search locations for human children and adults, Hermer and Spelke (1996) concluded the ability to use non-geometric information comes from some cognitive ability developed later in the human lifespan. This ability does not develop in rats since the children and adult rats (rat data used to compare came from previous studies) performed similarly. Language may be the developed mechanism Hermer and Spelke (1996) alluded to. An example of how non-geometric information may be represented linguistically may be via relational information. For example, “left of blue wall” (the trained location in Ratliff and Newcombe, 2008) is a linguistic form of understanding how a feature, blue wall, may be utilized to reorientate. Processing this information may be difficult in dual-task procedures however, as demonstrated by Ratliff and Newcombe (2008).

Strong evidence for language being the developed mechanism for utilizing non-geometric information was demonstrated by Lemer, Jones, Good, and Pearce (2003). Lemer et al. (2003) demonstrated that as human children learn more language their reorientation abilities also increase. Relational information, such as “left of blue wall”, has been shown to be disrupted by verbal shadowing task (Jung & Hummel, 2013). This relational information utilizes language learned as an individual learns his/her native language and effects reorientation abilities as demonstrated by Lemer et al. (2003). Frank, Fedorenko, Lai, Saxe, and Gibson (2012) found that linguistic mechanisms complement non-verbal encoding in a study utilizing quantity matching and verbal-shadowing tasks in English speakers and Pirahã speakers (whom have no words within their language to represent numbers). By studying the Pirahã, Frank et al. (2012) concluded language can be used to manipulate, store, and encode aspects of the environment, but language is an additive function of non-verbal representations which are not necessary. In other words, humans can utilize information and stimuli without the information being converted into a linguistic format. The finding also indicates that while the verbal shadowing task taxes attentional resources and possibly linguistic mechanisms, it does not necessarily affect mathematical mechanisms and high executive functioning that are involved in judgment and decisions making.

In a study conducted by Almaghyuli, Thompson, Ralph, and Jefferies (2012), synonym judgment tasks were shown to decrease both accuracy and reaction time in a dual-task setting. A synonym judgement task requires the participant to attend to and analyze information. Analyzing and making judgments places load on cognitive resources, specifically targeting central executive functions that are not targeted by shadowing tasks. Besner (1987) demonstrated that although suppression tasks such as shadowing do require attentional resources and linguistic mechanisms, but it does not necessarily interfere with the phonological loop when using written English as secondary task. Besner (1987) does concede that manipulation of the written information is disrupted by the suppression tasks. This indicates conscious processing is still available for the participant to use if the stimuli does not necessitate the same encoding mechanism.

The Adaptive Combination View

The discovery that different cues in the environment affect reorientation has led to the formation of another theoretical explanation for the reorientation phenomenon. Ratliff and Newcombe (2007) proposed what is referred to as the adaptive combination view. This view holds that reorientation will depend on the situation, species, saliency of features, geometric distinctions, as well as many other factors (some maybe even unknown to researchers as of yet). Whichever mode of orientation is the most adaptive at the time (i.e. most likely to yield the desired outcome) is the mode that will control reorientation behavior. Under this paradigm the ambiguity of the affine test can be explained in that if both geometric and featural cues are equally salient, then response allocation could be divided between locations consistent with geometric and feature cues. For example, during one affine test rats reoriented to the trained feature 47% of the time and to the trained geometrically correct location 47% of the time (Cheng, 1986). What this indicated was that the subjects used more than just the geometry of an environment to navigate. In a subsequent study, Sturz and Kelly (2013) demonstrated that the size of the environment influenced the reliance on featural cues, with more reliance in larger areas. This is not to say that the participants in the study (humans) could not still orient via geometry, which was demonstrated by above chance orientation to the correct geometric locations in the absence of featural cues (often referred to as a geometry test). Rather, these studies indicated how organisms adapt to and combine strategies in order to effectively solve problems, in this case reorientation and navigation in a given environment.

In order to explore the possibility that language is an underlying mechanism for reorientation, Hermer-Vazquez et al. (1999) tested university students in a verbal shadowing reorientation dual-task experiment. The participants in the study repeated verbal stimuli as they heard it (i.e., a shadowing task) while performing a reorientation task. One of the walls in the rectangular environment was shaded a different color, providing the participants both feature and geometric cues to utilize. The participants made more rotational errors when engaged in the verbal shadowing task compared to trials when not shadowing. Based on this finding, Hermer-Vazquez et al. (1999) concluded that the usage and manipulation of spatial information depended on the use of natural language.

Ratliff and Newcombe (2008) utilized the verbal shadowing task conducted by Hermer-Vazquez et al. (1999) and explored factors which may influence how human adults use cues when reorienting. The several experiments reported in Ratliff and Newcombe (2008) did not reproduce the findings of Hermer-Vazquez et al. (1999). When participants were given explicit instructions on what to attend to, the shadowing task had less of an inhibitory effect on reorientation in a large environment compared to the one used in Hermer-Vazquez et al. (1999). Additionally, performing a secondary spatial task while reorienting reduced feature usage as much as verbal shadowing (Ratliff & Newcomb, 2008). Thus Ratliff and Newcombe concluded language is not always necessary for reorientation, but rather accounted for their findings through the adaptive combination view. Working within the adaptive combination view paradigm, Ratliff and Newcombe (2008) explained these results by suggesting that both language and numerical knowledge could play a role in navigation together, depending on which is the best predictor of the goal at hand.

Both Ratliff and Newcombe (2008) as well as Hermer-Vazquez et al. (1999) used features as navigational cues, but did not conduct an affine test (shifting of the featural cue) in order to place the featural and geometric cues in conflict with each other. Language can also be used to describe the geometry of an enclosure such as “long wall”, “short wall”, “large corner angle”, and “small corner angle”. All of these descriptive phrases in a geometric task may be represented through language, but in order to come to these conclusions a size comparison must be done. In other words these are language representations of numerical/mathematical comparisons. By not conducting the affine, test Hermer-Vazquez et al. (1999) and Ratliff and Newcombe (2008) might not have received the expected decrease in performance because the mathematical centers for orientation and higher conscious processing powers were still available to the individual even during a language dual-task. The lack of decrease in expected orientation is an argument against language being a necessity in order to orientate.

Almahasneh, Chooi, Kamel, and Malik (2014) used a dual-task method for both a mathematical problem and word problem solving, and measured frontal lobe activity using an electroencephalograph (EEG). Participants drove in a simulated course with designed distance judgment points (gaps to drive through). While driving participants solved either math equations (in the form of word problems) or logical reasoning analogies, and EEG data was collected. What Almahasneh et al. (2014) found was that there was significant increased activity associated with the right frontal lobe during the math task while as the verbal task increased activity in both the right frontal lobe and the left frontal lobe. The dual-tasks did produce poorer driving performance (e.g., not keeping inside a lane and accidents) compared to a baseline. The authors however did not explore the two tasks separately to determine if one produced worse driving compared to the other. Almahasneh et al. (2014) also did not analyze the results to determine if any of the driving errors were linguistic, mathematical, or decision based and if those errors were systematically related to the dual-task condition. This analysis may shed light on the different neurological activation reported; different brain regions are often associated with different cognitive functioning (e.g., the frontal lobe is associated with conscious thought and decision making).

Many complex, organized behaviors and working memory are linked to the frontal lobe (Kimberg & Farah, 1993). Almahasneh et al. (2014) found different frontal lobe activity for different forms of dual-task activities while driving. Differences in brain activity and driving performance may indicate that different mechanisms for navigation are inhibited by the different dual tasks; consistent with the adaptive combination view. Dual tasks were developed in order to create competition and to place demands on cognitive resources (for a discussion on this topic see Radvansky & Ashcraft, 2014). If the cognitive resources being placed under competition are relevant/necessary for the primary task at hand, then performance in one or both of the tasks should drop significantly when in a dual task situation (e.g., Logie, Zucco, & Baddley, 1990). Chaparro and Carberry (2005) show evidence that mathematical dual tasks inhibit gap judgment abilities, which indicates that the ability to distinguish distance from one point to another has an underlying mathematical mechanism. Understanding the geometry of an environment is irrevocably tied to an organism's ability to make judgments about space between one point in an environment and another (see Kelly, Durocher, Chiandetti, & Vallortigara, 2011 for an explanation of two theories of reorientation by geometry heavily reliant on this concept). The ambiguous results when looking at Ratliff & Newcombe (2008) and Hermer-Vazquez et al. (1999) combined indicates there is a decrease in human ability to navigate via features or geometry when linguistic mechanisms are overloaded. The means by which this overload may effect reorientation is still unclear. The evidence presented by Almahasneh et al. (2014), Chaparro and Carberry (2005), and Kimberg and Farah (1993) lend some neurological support for specific brain functioning dedicated to certain tasks, but the mechanisms are not as modular as Cheng (1986) originally assumed. These mechanisms appear to be involved in many similar cognitive functions, which explain decreased performance associated with general cognitive resource strains.

It is possible that if attentional resources utilized for a linguistic mechanism are devoted to another task, then other mechanisms may need to be engaged for orientation purposes (e.g., a mathematical mechanism). Within the context of the Adaptive Combination View attentional demands required to perform a shadowing task diminishes the ability to reorientate, or perform another task in general. Villiers (2014) utilized a linguistic shadowing and tapping shadowing task (tapping of the hand on a surface to the given rhythm to be shadowed) to provide evidence that language is not the key to the primary task deficits. The tapping and linguistic shadowing did not significantly differ in their effect on a primary task, indicating that the attentional demands alone are the critical aspect of the shadowing task, not the linguist aspect (Villiers, 2014). Wegbreit, Suzuki, Grabowecky, Kounios, and Beeman (2012) demonstrated that the attentional demands of dual-task paradigms consume cognitive resources necessary in completing visual-based tasks as well as verbal problem-solving tasks in a standard laboratory setting; consistent with the driving dual-task studies reported by Almahasneh et al. (2014) and Chaparro and Carberry (2005).

Working Memory

Both the Language as a Bridge and Adaptive Combination View accounts could be viewed as different working memory approaches to explain the reorientation phenomenon. In order to directly compare these two accounts it is useful to place both accounts into the same working memory model for direct comparison. The working memory model which could fit both models and possibly provide distinct predictions for both accounts is Baddley's (2000) Working Memory Model. In Baddley's (2000) Working Memory Model the phonological loop and visuospatial sketchpad are constructs representing temporary storage of information for further encoding and manipulation. The phonological loop is specifically for auditory storage and manipulation. The visuospatial sketchpad serves to store and manipulate visual and mathematical information. Both the visuospatial and phonological constructs are heavily dependent on attentional resources. Tasks which require a lot of attention, such as a shadowing task, will prevent other information from being available or encoded for use if they correspond to the construct already in use. The central executive allocates attentional resources to the phonological loop and visuospatial sketchpad as well as utilizes conscious processing resources in order to make decisions. The episodic buffer also uses conscious processing resources in order to allow information to flow directly from the visuospatial sketchpad to the phonological loop and vice versa. Baddley’s (2000) model proposes language is a key component for how the episodic buffer transitions each construct’s components into integrated and transferable information.

If I place the Adaptive Combination View and Language as a Bridge theories into Baddley’s (2000) Working Memory Model I would expect the each to operate on different levels of processing. The Adaptive Combination View focuses on what information is attended to and encoded as the best predictor of successful orientation. Thus the Adaptive Combination View would be expected to operate on the attentional level of the Working Memory Model. The phonological loop and visuospatial sketchpad fulfill the different mechanisms which may be utilized depending on best predicting factors and attentional resources available described by the view. On the other hand Language as a Bridge describes the conscious processing and cross communication language is already theorized to do in the episodic buffer under the Working Memory Model.

Unlike Cheng’s (1986) Geometric Module, Baddley’s (2000) Working Memory Model is not a modular theory. The Working Memory Model is used to understand many different cognitive processes, all of which utilize mental resources such as attention or conscious processing. By placing reorientation theories into this model researchers are able to utilize the existing knowledge regarding dual-task paradigms and the resource limitations already theorized. By considering reorientation as another resource drain, and not a separate automatic process, detriments in performance already seen under dual-task conditions are predictable based on the type and difficulty of the two tasks being performed simultaneously.

Purpose of the Study

The current study is aimed at partially replicating the Ratliff and Newcombe (2008) and the Hermer-Vazquez et al. (1999) studies while specifically targeting the executive functioning of the experimental group instead of more general overloading of attentional resources. I expect the control group to show no preference for the geometrically trained response location on an Affine test (featural cue shifted), but to show a preference for the geometrically trained response location during a Geometry test (no featural cue) when in a virtual environment. The experimental group will be completing a synonym judgement task while reorienting in a virtual environment. I expect the experimental group to show a preference for the geometrically correct response location in both the Affine and Geometry tests. I expect this because the resources for higher cognitive functions necessary to create, encode, and utilize the linguistic relational information will be already taken by the synonym judgement task. Due to this resource strain the experimental group must utilize non-verbal representations of information in the environment, the geometry of the environment. By demonstrating this I aim to show that Language as a Bridge and the adaptive combination view operated on two different levels of processing: automatic encoding (attentional) and conscious processing.

CHAPTER 3

METHODS

Participants

There were 33 participants in the study; 20 females and 13 males. The participants were undergraduate students from Georgia Southern University. Participants received class credit for their participation in the study.

Apparatus & Materials

An interactive, dynamic three-dimensional virtual environment was constructed and rendered using the Valve Hammer Editor and was run on the Half-Life Team Fortress Classis platform. A personal computer, 21” flat-screen liquid crystal display (LCD) monitor, gamepad with joysticks, and speakers served as the interface with the virtual environment. The monitor (1,152 × 864 pixels) provided a first-person perspective of the virtual environment. Participants used the joystick on the gamepad to orientate within the environment. Speakers emitted auditory feedback for goal location choice during training trials as well as the synonym judgment task stimuli (utilizing PowerPoints’ audio record function). Experimental events were controlled and recorded using a Half-Life Dedicated Server on an identical personal computer. See *Figure 2* for pictures of the experimental environments.

Distractor tasks were run on an identical computer using Microsoft Power Point and speakers. Each synonym pair was voice recorded onto an individual slide. The slides change automatically on varying intervals, with audio playing at onset of the new slide. The interval for each slide was dependent on how long it took to present the synonyms. Each slide is constructed such that there is 3 seconds of time between the end of one problem and the beginning of the next slide; during this time the participants evaluated and responded to the word pair.

The linguistic distractor task utilized words from the English language. Whether the word pair is a synonym or not was randomized throughout the task.

Procedure

Participants were randomly assigned to either the Control condition (*n* = 16) or the Language Dual-Task (LDT) condition (*n* = 16).

Response coding for the dual-tasks had three possible outcomes: True, False, and no response. Responses were recorded by an experimenter in Microsoft Excel.

The navigational environment consisted of a rectangular area with wall lengths analogous to 14 m X 28 m. Four uniform cubes located in the corners of the rectangle were utilized as goal locations (one per corner). Participants could see beyond the enclosure, giving them a global perspective of the environmental shape. The participant reorientated, via gamepad, by spinning around in the center of the enclosure. The participants utilized the gamepad's joystick to: rotated view left (←), and rotated view right (→). Participants entered the rectangular enclosure at random orientations from 0° to 270° in increments of 90°. Participants selected goal locations by pressing either the bottom right or bottom left trigger on the gamepad while aiming toward the desired location (this triggered a shooting animation within the virtual environment). During Training trials, correct goal selection ended navigation and loaded the next environment, providing a 7-s inter trial interval (ITI) and produced auditory feedback (bell sound). Incorrect goal location responses during Training trials produced a buzz sound and indicated that reorientation was not complete. During test trials all goal locations ended navigation with no auditory feedback. During training trials one wall was shaded darker than the other three (see *Figure 2* A). The goal location was to the left of this wall. All goal locations were uniform. These procedures are consistent with previous reorientation literature (Bodily, Kilday, Eastman, Gaskin, Graves, Roberts, & Sturz, 2013; Sturz & Kelly, 2013; Bodily, Eastman, & Sturz, 2011; Sturz & Bodily, 2011).

Training trial responses are coded as thus: Top Left (TL) = Correct, Bottom Right (BR) = Incorrect, Top Right (TR) = Incorrect, and Bottom Left (BL) = Incorrect. Test trial responses were coded as: Correct or Incorrect. The Correct (TL) and Rotational Equivalent (BR) response locations are geometrically identical to each other, and therefore are two Correct response locations for Test trials, but only one Correct response location for Training trials. The Incorrect response locations (TR and BL) are also geometrically identical to each other, and thus were both be coded as Incorrect during test trials. Test trials consisted of a Geometry test (see *Figure 2* B) in which no feature information is provided, and an Affine test (see *Figure 2* C) in which the feature is shifted 90 degrees clockwise in the environment. The response information is extrapolated from the running game code and triggered locations within the Half-Life server logs.

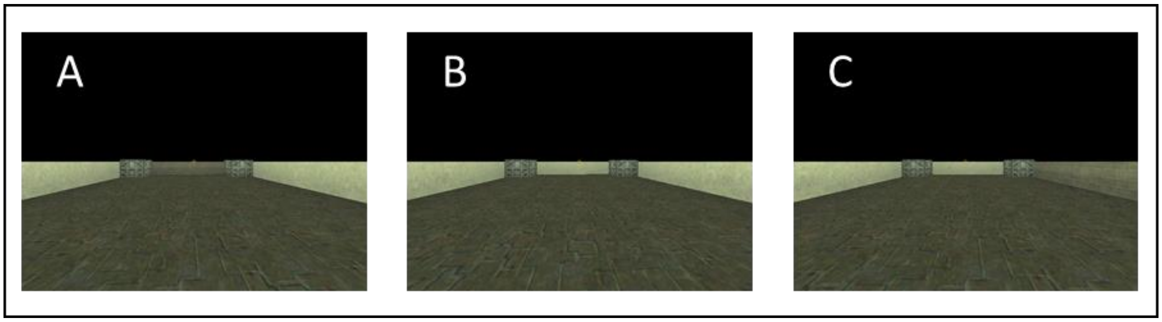

Figure 2. A) The participant's view of the virtual environment during training trials. The geometry of the enclosure and the shaded wall serve as orientation cues for the participant to acquire the task. The task is to respond (via shooting a virtual laser gun) to the box on the left side of the shaded wall, the Top Left corner of the enclosure. B) An example of the participant's view of the experimental environment. This particular shot is of the Geometry Test in which the featural cue (shaded short wall) has been removed from the environment. C) Participant view of the Affine test. The box to the left of the picture is the trained location (Top Left).

Training trials were grouped into blocks of 2 trials in order to analyze acquisition. Participants in the Control condition who did not acquire the task within the first 8 training trials (4 acquisition blocks), indicated by 100% response to the correct location on the first attempt in the last training block (Block 4), were dropped from analysis. Further, one who did not answer 17 synonym pairs within the LDT condition was dropped from the analysis. Two participants who did not use True or False to provide responses were also dropped from the analysis. One participant was dropped due to technical issues with the program. One participant never learned to orient within the environment (never shot the correct target to get past the first environment after 15 minutes) and was dropped from analysis.

Predicted Results

Utilizing the synonym judgement task should allow us to separate the Adaptive Combination View and Language as a Bridge if they indeed are processed differently under Baddley's (2000) Working Memory Model. The Control condition was predicted to acquire the task above chance levels by the end of acquisition training. The Control condition was further predicted to show control of geometry by orienting to the geometrically correct locations above chance levels during the Geometry test condition. Control condition participants were further predicted to show neither control by feature or geometry by orienting to both geometrically correct and feature correct location at about chance levels for the Affine test. These predictions are consistent with previous findings.

The LDT condition was predicted to acquire the task above chance levels by the end of acquisition training. If I have interpreted the Language as a Bridge theory correctly, the judgement task should not disrupt the encoding of information and therefore I predicted the LDT participants to show control by geometry in the Geometry test as well as to show chance level responses to the geometric and feature correct locations in the Affine test. Under the Language as a Bridge theory the phonological loop and visuospatial sketchpad are available for basic encoding and storage purposes, but more complex manipulations may be disrupted due to lack of conscious processing resources. I expected to see a significant latency difference between groups for the Geometry and Affine test due to conscious process resources being taxed in the LDT condition.

If the Adaptive Combination View is controlling reorientation I expected to see the LDT condition show control by geometry in both the Affine and Geometry tests. I predicted this because they synonym judgement task is being presented via audio and therefore will utilize some phonological loop resources. If enough resources are utilized than only visual information, such as enclosure geometry, will be available for orientation purposes. If there are enough resources leftover from performing the judgement task, as it does not demand as many attentional resources as a shadowing task, then I would expect the LDT to not perform significantly different from Control on either Geometry or Affine test.

If the synonym judgement task is too difficult it is possible the LDT condition does not acquire the task and does not show control by any orientation cues during testing.

CHAPTER 4

RESULTS

Acquisition to Trained Location

A 2 X 12 mixed Analysis of Variance (ANOVA), Condition (Control, LDT) X Training Block (1 – 12) was used to analyze response to the trained TL location for all participants in both conditions whom met inclusion criterion prior to analyzing for Block 4 acquisition. There was no main effect of Condition, $F(1, 24) = 1.02$, $p = .32$. There was a main effect of Training Block, $F(11, 14) = 5.79$, $p < .001$. There was no significant interaction, $F(11, 14) = .86$, $p = .58$. For graphical representation see *Figure 3*.

After looking into Block 4 acquisition I realized only 2 Control participants met training inclusion criteria (100% reorientation to the TL location during Block 4). Upon further investigation I discovered 12 total Control participants reoriented to a geometric (TL or BR) location 100% of the time during Block 4. All further analysis are using the 12 participant Control group.

All forthcoming analysis should be read with caution as the participants used did not actually acquire the trained task presented. Since the participants cannot be shown to have learned the task presented the Geometry and Affine tests cannot be utilized as originally intended. The Control condition did not appear to cue onto the feature and thus I cannot assume the LDT participants did either. With only one orientation cue controlling behavior both Language as a Bridge and Adaptive Combination View will predict the participants should still utilize geometry to reorientate under the synonym judgement dual task as the visuospatial sketchpad is available for use under both accounts. The only difference possibly seen would be in latency with the Language as a Bridge taking longer than control to complete tasks due to conscious processing strains, whereas the Adaptive Combination View should not see latency differences between Control and LDT since the visuospatial sketchpad attentional resources are not under any strain due to a dual task.

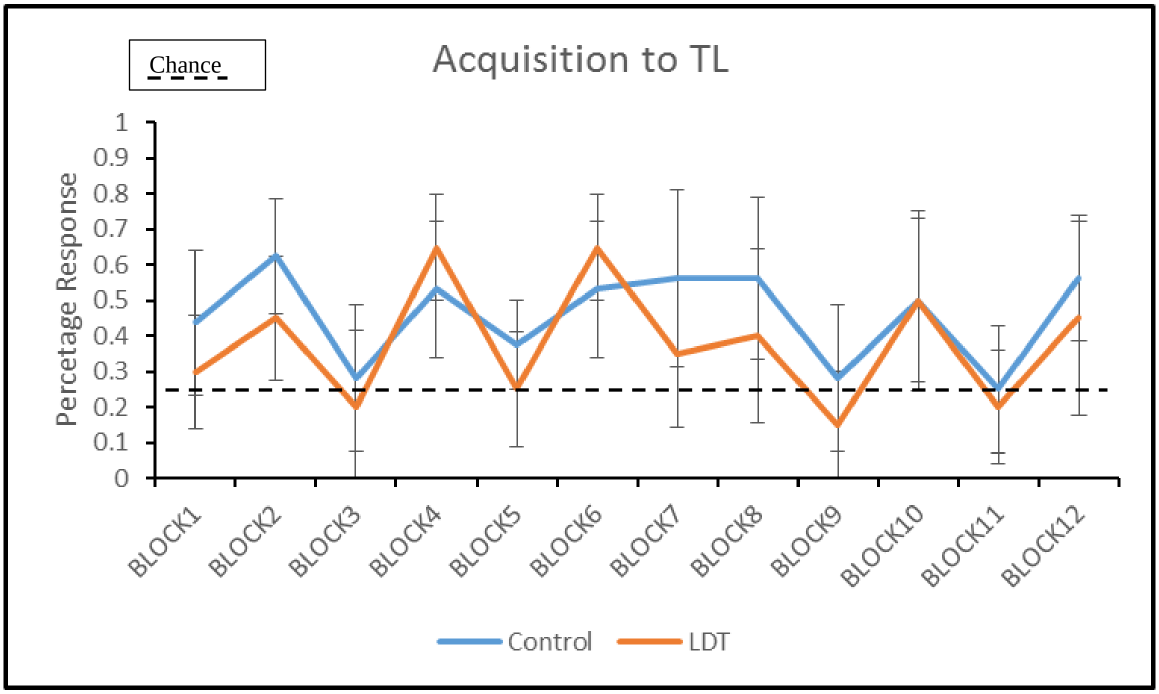

Figure 3. First response to the Top Left, trained, location during all training blocks. Error bars indicate 95% confidence intervals.

Response Allocation

Before analysis were conducted, one sample *t*-tests were run on Block 4 of training trials for each condition in order to examine if each group learned to respond to the correct geometric locations prior to testing conditions. Both conditions responded to the geometrically correct locations significantly above chance levels (.5). The Control group responded to the correct locations 100% of the time during Block 4 (*M* = 1, *SE* = 0), while LDT also responded above chance levels, *t*(9) = 2.45, *p* < .05 (*M* = .70, *SE* = .082). Both conditions learned to respond to a geometrically correct location.

A 2 X 2 mixed Analysis of Variance on percent choice allocation to the geometrically correct location with Condition (Control, LDT) as the between-subjects factor and Test (Geometry, Affine) as the within-subjects factor which revealed a significant main effect of Condition, *F*(1, 20) = 11.42, *p* < .01. No significant main effect of Test, *F*(1, 20) = 1.61, *p* = .22, or interaction, *F*(1, 20) = .24, *p* = .63, were found. Overall the Control condition (*M* = .833, *SE* = .056) responded to the geometrically correct locations more often than the LDT condition (*M* = .55, *SE* = .061). Subjects did not respond significantly different between the Geometry (*M* = .76, *SE* = .256) and Affine (*M* = .65, *SE* = .349) test. Responses for the Control condition the Geometry test (*M* = .861, *SE* = .064) did not differ from the Affine test (*M* = .806, *SE* = .096). For the LDT condition responses for the Geometry test (*M* = .633, *SE* = .078) did not differ from the responses to the Affine test (*M* = .477, SEM = .089). See *Figure 4* for graphical representation.

To compare the Test trial response allocations to chance, one sample *t*-tests were run on the collapsed response locations (TR/BL combined and TL/BR combined) for both Control and LDT conditions to examine if the geometric locations were responded to above chance levels (.5) for both the Geometry and Affine tests. In order to examine this each test trial was placed into the analysis as its own line. With 3 test trials of both Geometry and Affine test the degrees of freedom are minus one of three times the number of participants. For the Control condition Geometry test the TR/BL locations were responded to significantly less than chance, *t*(35) = -6.18, *p* < .001 (*M* = .14, *SE* = .058), and TL/BR were responded to significantly above chance, *t*(35) = 6.18, *p* < .001 (*M* = .86, *SE* = .058). The Control condition participants responded to the geometrically correct locations significantly above chance for the Affine test as well; TR/BL t(35) = -4.57, p < .001 (*M* = .19, *SE* = .067) and TL/BR t(35) = 4.57, *p* < .001 (*M* = .86, *SE* = .58). The LDT condition participants responded to the TR/BL locations at chance levels for the Geometry test, *t*(29) = -1.49, *p* = .15 (*M* = .37, *SE* = .089), and to the TL/BR locations at chance levels, *t*(29) = 1.49, *p* = .15 (*M* = .63, *SE* = .089). The LDT participants also responded to the TR/BL locations at chance levels, *t*(29) = .36, *p* = .72 (*M* = .53, *SE* = .093), and to the TL/BR locations at chance levels, *t*(29) = -.36, *p* = .72 (*M* = .63, *SE* = .089), for the Affine test. This indicated the Control was influence by geometry whereas the LDT condition showed no indication of utilizing geometric cues (see *Figure 4*). The LDT condition responding no differently than chance is indicative of random responding whereas the Control condition above chance response to the geometrically correct locations is indicative of usage of geometric cues for reorientation.

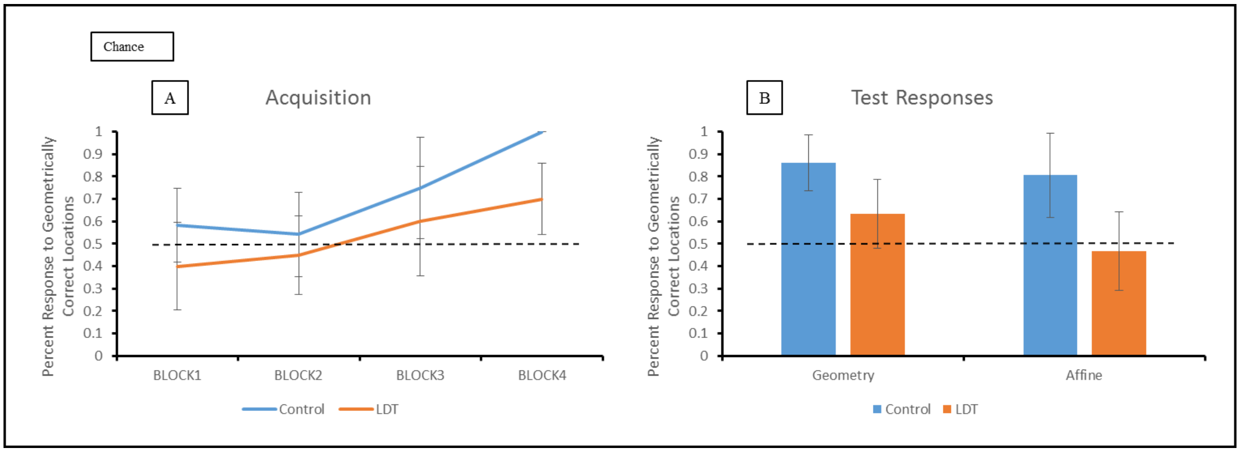

Figure 4. A) Acquisition across training blocks for Control and LDT conditions. Control reached 100% correct with 0 variance during Block 4. LDT condition was responding to the correct locations above chance levels in Block 4. B) Responses to the geometrically correct locations during the Affine and Geometry tests for both conditions. Control responded to the geometrically correct locations above chance levels for both tests. LDT condition responses Ire at chance levels for both tests. Error bars indicate 95% confidence intervals.

To further analyze what features were influencing the behavior of the participants I conducted one sample *t*-tests for each separate response location within the Affine test. Similar procedures were used to analyze the individual response locations, but instead of .5 chance level the comparison chance level was set to.25. The analysis indicated that for the Control condition the TR, *t*(35) = -1.32, *p* = .19 (*M* = .17, *SE* = .063), and the TL, *t*(35) = .00, *p* = 1.00 (*M* = .25, *SE* = .073), were not significantly different from chance. The BL, *t*(35) = -8.00, *p* < .001 (*M* = .028, *SE* = .028), and BR, *t*(35) = 3.64, *p* = .001 (*M* = .56, SE = .084), were both significantly different from chance. The BL location was responded to significantly less than chance and the BR location was responded to significantly above chance levels for the Control condition. For the LDT condition no location was responded to significantly different than chance: TR *t*(29) = -1.85, *p* = .08 (*M* = .13, *SE* = .063), BL *t*(29) = 1.65, *p* = .11 (*M* = .40, *SE* = .091), TL *t*(29) = -1.85, *p* = .08 (*M* = .13, *SE* = .063), BR *t*(29) = .95, *p* = .35 (*M* = .33, *SE* = .088). This further analysis indicated there was control by Geometry for the Control condition, but the LDT condition did not significantly fall under any cue influence, (see *Figure 5*).

Latency

A 2 X 4 mixed ANOVA was used to compare the average latency means for each acquisition Block (Blocks 1 – 4) across Conditions (Control, LDT). There was no main effect of Condition, *F*(3, 20) = 1.53, *p* = .23. There was a significant effect of Block, *F*(3, 20) = 6.47, *p* < .05. There was a significant interaction of Condition and Block, *F*(3, 20) = 4.93, *p* < .05. Post-hoc independent samples *t*-test indicated there was a significant difference between Conditions in Block 1, *t*(20) = -2.27, *p* < .05, but not Blocks 2-4. LDT participants took significantly longer to complete Block 1 compared to Control participants, but did not take longer for Blocks 2-4.

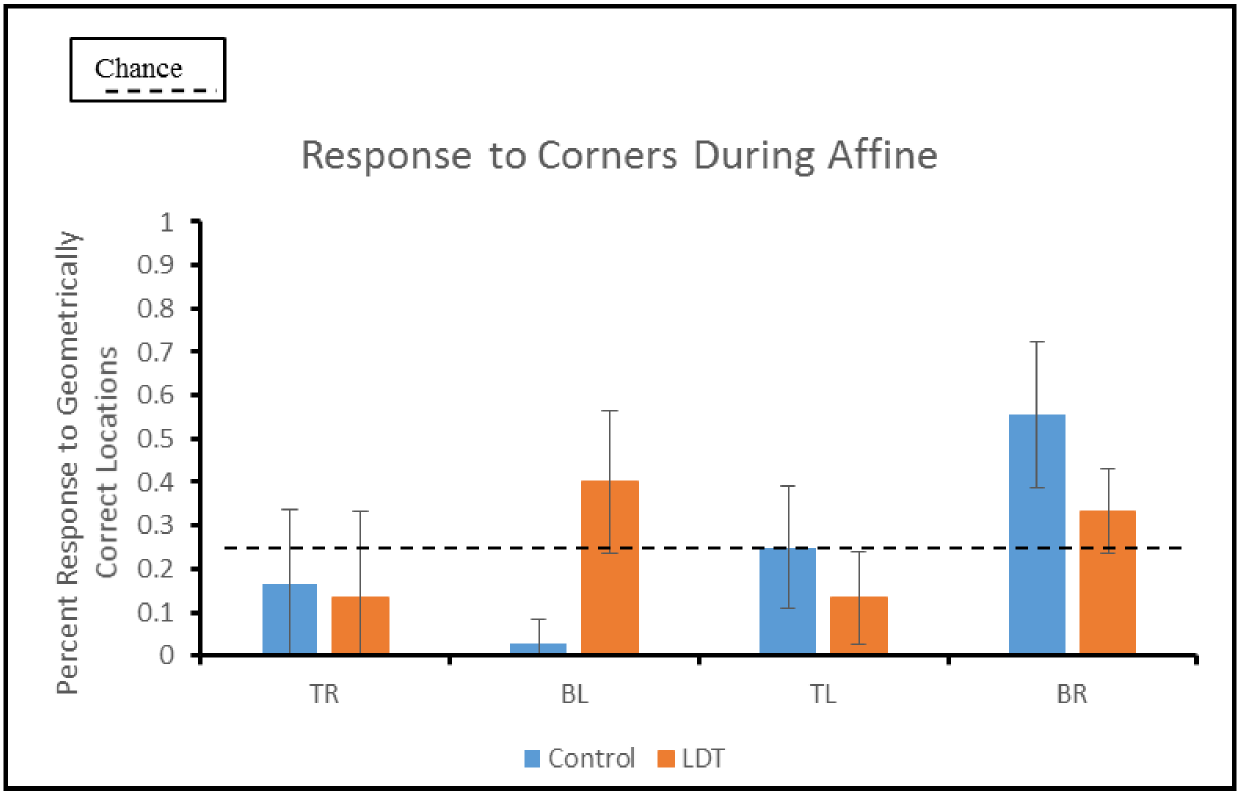

Figure 5. First Response to individual response locations across Affine test trials. All locations are equal to random chance except to the Bottom Left (BL) and Bottom Right (BR) locations. BL is significantly below chance levels and corresponds to no trained orientation cue. BR is significantly above chance levels and is the rotational equivalent of the geometrically trained location as Ill as adjacent to the rotated feature. Error bars indicate 95% confidence intervals.

Post-hoc paired samples *t*-test indicate the latency significantly decreased from Block 1 (*M* = 30.70, *SE* = 8.83) to Block 4 (*M* = 9.1, *SE* = .81) during acquisition for the LDT condition, *t*(18) = 2.44, $p < .05$. In contrast the Control condition Block 1 (*M* = 12.00, *SE* = 1.69) and Block 4 (*M* = 11.75, *SE* = 0.81) latencies did not differ significantly, *t*(22) = .06, *p* = .95. These results indicate that the Control group latency stayed constant throughout acquisition, while the LDT group latency declined throughout acquisition. Furthermore, the data indicates the LDT responded slower when presented the environment for the first time, but after repeated exposure responded faster, see *Figure 6*.

I used a 2 X 3 mixed ANOVA in order to examine the latency of Condition (Control, LDT) and Trial Average (Training Post-acquisition, Geometry Test, Affine Test) in order to test if LDT condition participants took longer to complete trials compared to Control. There was a main effect of Trial, *F*(2, 20) = 4.79, $p < .05$. There was no main effect of Condition, *F*(1, 20) = .18, $p = .68$. There was a significant main effect of Trial Average, *F*(2, 20) = 4.79, $p < .05$. There was a significant interaction, *F*(2, 20) = 4.01, $p < .05$.

Post-hoc paired samples *t*-tests were run to analyze the means of each Test's latency within conditions. Paired samples *t*-tests indicate the latency was significantly different between Geometry (*M* = 9.6, *SE* = 1.07) and Affine (*M* = 4.1, *SE* = .41) for the LDT condition, *t*(18) = 8.004, $p < .001$. There were no differences between the Geometry (*M* = 5.33, SEM = .59) and Affine (*M* = 5.08, *SE* = .59) test latencies for the Control condition, *t*(22) = 1.29, *p* =.22. There were also significant differences between the Post-acquisition Training Trials (*M* = 7.00, *SE* = .54) and Affine for the LDT condition, *t*(18) = 5.75, $p < .001$, so that there was less latency for the Affine test. No significant differences between Post-acquisition Training Trials (*M* = 8.58, *SE* = 2.62) and Affine test were found for the Control condition, *t*(22) = 1.53, *p* =.15. Significant differences between the Post-acquisition Training Trials and Geometry test for the LDT condition were also found, *t*(18) = -3.03, $p < .05$, such that it took more time to complete the Geometry test than the Training trials. No differences between Post-acquisition Training Trials and Geometry test were found for the Control condition, *t*(22) = 1.29, *p* =.24. The LDT condition took less time to complete the reorientation task in the Affine test compared to the Geometry test and Post-acquisition Training trials, longer to complete the Geometry test compared to Post-acquisition Training trials, while the Control condition did not differ in time to complete tests or trials (see *Figure 6*).

Independent samples *t*-tests were used to analyze the difference latencies between conditions for each trial type. Results indicate no significant difference between conditions for the Post-acquisition Training trials, *t*(20) = .541, *p* = .59, and no significant difference for the Affine test trials, *t*(20) = .149, *p* = .21. There was a significant difference between conditions for the Geometry test trials, *t*(20) = -3.65, *p* < .05, with the LDT condition taking longer to complete the trials. An independent samples *t*-test was also run for the total study latency, not including the 7 second ITI. There were no significant differences between conditions, *t*(20) = -.013, *p* = .99. See *Figure 6* for graphical representation of the data.

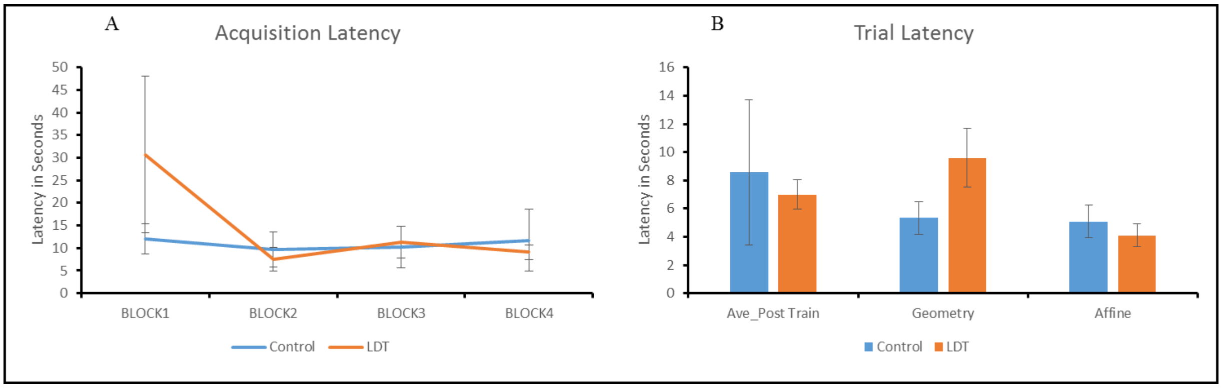

Figure 6. A) Shows latency during acquisition training trials. Control and LDT Ire significantly different for Block 1. B) Compares latency of the Geometry and Affine test to the average latency for Post-acquisition Training trials. Error bars indicate 95% confidence intervals.

CHAPTER 5

Discussion

Results of the analysis indicate the synonym judgment task altered the reorientation behavior of the participants in this study. Participants in the LDT condition were able to acquire orientation to the geometrically correct locations just as the Control condition did, but unlike the Control condition, the LDT participants did not orient to those locations during either the Geometry or the Affine tests. During test trials LDT participants responded to response locations no different than randomly selecting a location. Control condition participants responded to the geometrically correct locations more often than would be expected from random chance during both the Affine and Geometry tests. Participants were slower to find the first correct response location, but did not differ from the control in subsequent training trials thereafter. Control condition participants did not differ in their response latencies for any trial, test or training, after the task had been acquired. LDT participants on the other hand were slower than training trials post acquisition when completing the Geometry test, and faster when completing the Affine test.

The Control condition not acquiring the response location which matched with both geometry and feature cues in the orientation task fits in line with the adaptive combination view stance. The featural cue for this study may not have been sufficiently salient for the feature to be considered a predictor of the correct response location, whereas geometry information was. Therefore, the participants responded to the first geometrically correct response location regardless of the feature. In other words the mechanisms for extrapolation of geometric information were sufficient for reorientation such that the low salient feature information was ignored.

If I examine the collapsed rotational equivalent response locations I find evidence for language based judgement tasks interfering with the ability to reorient via geometry. Since the feature may not have been salient enough to control orientation in the Control group I presume that this would also be the case for the LDT condition as well. Both Control and LDT conditions were able to orient to a geometrically correct location, accuracy, above chance levels during training, but the LDT condition reoriented to the geometrically correct locations significantly below the levels of the Control condition. The LDT, although above chance levels, performed significantly worse than the Control condition. Therefore the synonym judgment task reduced the ability of the LDT group to reorient via geometry. This inability to orient via geometry during training for the LDT condition is further indicated by the Geometry test where the Control condition oriented to the geometrically correct locations significantly more than chance while the LDT condition did not respond to those locations different than chance.

Since the LDT condition was able to acquire reorientation via geometry during training I rule out the possibility that the synonym judgement task required to many resources to block initial encoding of environmental information. The participants in the LDT condition responded at chance levels to the geometrically correct locations in both the Geometry and Affine tests. This could be indication that orientation in new environments requires conscious processing, which was not available. Since I cannot utilize the Geometry and Affine tests as originally intended, to pit the orientation cues into conflict and remove one, I cannot make any assumptions of what cues were utilized and what mechanisms may correlate to each cue.

There are two possible explanations based on the Language as a Bridge theory for how the synonym judgment task may have inhibited the participants' ability to orient via geometry. First, the linguistic nature of the task may have inhibited the participants' ability to convert the geometric information and relationships into a usable linguistic format. This would indicated that language is necessary for reorientation no matter what kind of cue is presented. The second explanation is the judgment task required to many resources of the central executive in order to make an accurate judgment based on the geometric information received. Under this explanation language is not necessary because the judgment is utilizing other processes and the key part is the lack of resources available to make an accurate judgment. In order to test these two competing explanations future research should conducted with reorientation tasks in three conditions: Control, Language Judgment, and Math Judgment. The Language Judgment condition would be a synonym judgment task (i.e., a verbal task), the Math Judgment condition would utilize non-verbal forms of math. For example, the Math Judgment condition could utilize various forms of approximate numerical judgments used throughout the literature in research on the Approximate Number System (e.g. Feigenson, Dehaene, & Spelke, 2004; Halberda & Feigenson, 2008; Nys, Content, and Leybaert, 2013). Nys, Content, and Leybaert (2013) demonstrated that these approximate tasks are not dependent on language by testing children with various forms of language impairment and comparing their results to other children without language impairment. Nys et al. (2013) found that exact number representations rely on language, but approximations do not. By comparing a linguistic decision and a purely mathematical decision it can be determined if reorientation ability relies on executive functioning in general, or if language is a necessary component of the process. If executive functioning is the key to the reorientation process, than one might interpret the results to mean generalization to new environments does not occur under such conditions. This is supported by the current study because the LDT participants were able to acquire orientation by geometry during training, but did not do so in the Geometry test (no feature), or Affine test (shifted feature) environments.

During the Affine test, the Control condition responded to the geometrically correct locations significantly more than chance, but interestingly most often to the Rotational Equivalent location. The Rotational Equivalent location was adjacent to the shifted feature, but on the opposite side of the feature compared to the correct location during training. The LDT condition responded to the geometrically correct locations at chance levels for the Affine test, but their latency was significantly faster compared to the Geometry test. Taking this information together I believe the feature of the Affine test may have become salient enough to influence reorientation, possibly due to the feature wall doubling in size from training to Affine. The Control condition continues to respond to a geometrically correct location, but disproportionately towards the location adjacent to the featural shift. The two cues may have worked together to influence reorientation to the BR location significantly above chance. Meanwhile the BL location, which has neither feature nor geometric cue associated with it, was responded to significantly below chance. This combining and utilizing multiple cues to reorient fits the narrative of the adaptive combination view. With a feature becoming a salient orientation cue the LDT participants may have interpreted the environment as a completely new area, and therefore not utilized the orientation rules learned during training.

The slow response latency for the LDT participants when presented with the Geometry test environment and the first training trial indicate slower processing of information. The rapid response in the Affine test by the LDT condition may be due to feature gaining saliency. With a novel, and salient, feature the participants may not be making a decision based on previous experience, but rather randomly choosing a response location in order to discover the cues which dictate orientation in the novel environment. This indicates a lack of generalization from training environment to testing environment. Generalization of information may be controlled based largely upon executive functioning mechanisms which were already taxed for resources due to the synonym judgment task.

By demonstrating that geometric information could be encoded and utilized in training even under conditions taxing executive functioning resources I have shown evidence that the Adaptive Combination View and Language as a Bridge theories may operate on different cognitive levels. Specifically, the Adaptive Combination View may operate on an attentional level whereas Language as a Bridge may operate on a conscious processing level. Further research needs to be done to see if language is actually a bridge necessary for orientation via geometry. Future research also necessitates synonym judgement task and verbal shadowing tasks be directly compared to explicitly compare the two theories.

CHAPTER 6

Limitations

Limitations of this study include small sample size, possibly an atypical subject pool, and low saliency of a manipulated variable. This study only had 22 participants after adjusting the initial inclusion criteria. Consequently statistical power is low. The subject pool was comprised of college students who are arguably better at making linguistic and mathematical decisions due to years of academic experience, when compared with the general population. Therefore our population may require fewer mental resources to accomplish the tasks compared to the general population. This would possibly lead the subject pool to perform better than the general population. Lastly, the featural cue intended to serve as a linguistic orientation cue may not have been sufficiently salient to serve as an orientation cue. Future research should ensure that any reorientation cues used are salient enough to be utilized, especially when comparing different such as in the Affine test.

Since the Control condition did not acquire the orientation task to a level normally expected, I cannot interpret the tests as originally intended. The previous interpretations of the data are subject to alternative assumptions which may or may not hold true for the general population.

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