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The Development of Spatial Vocabulary

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

THE DEVELOPMENT OF SPATIAL VOCABULARY

A dissertation submitted in partial fulfillment of the
requirements of the degree of

DOCTOR OF PHILOSOPHY

in

PSYCHOLOGY

by

Rosalie Odean

2018

To: Dean Michael R. Heithaus
College of Arts, Sciences and Education

This thesis, written by Rosalie Odean, and entitled The Development of Spatial Vocabulary, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Date of Defense: March 21, 2018

The thesis of Rosalie Odean is approved.

Dean Michael R. Heithaus
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Vice President for Research and Economic Development
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Florida International University, 2018

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DEDICATION

I dedicate this dissertation to my nephew Samuel Crawshaw, for reminding me how interesting development can be.

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I have been incredibly lucky to have the support of many smart and giving people throughout the process of completing this dissertation. First, I must thank my advisor Dr. Shannon Pruden for her support and enthusiasm for the project from the earliest idea of a new measure through the final draft. This project would be much weaker were it not for the guidance of my committee members, Drs. Eliza Nelson, Stefany Coxé, and Virginia Mueller Gathercole.

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ABSTRACT OF THE DISSERTATION
THE DEVELOPMENT OF SPATIAL VOCABULARY

by

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Miami, Florida

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Previous research has shown a link between the spatial words children use and their performance on spatial reasoning tasks. There is a dearth of measures of spatial language, especially those that focus on a specific type of word. This dissertation introduces three studies, using two measures of dimensional adjective comprehension, one in English and one in Spanish. Study one found that bilingual children's knowledge of dimensional adjectives in one language is not predictive of their performance on dimensional adjectives in the other language, but that general vocabulary within a language predicts performance in that language. This study also showed that within a pair of polar opposite terms (e.g., long and short) children are more likely to know the term describing the big dimension and not the small dimension than vice versa. The second study found that the number of dimensional concepts children comprehend predicts how well they perform on a spatial scaling test, controlling for age and general vocabulary. The final study failed to find a link between dimensional adjective knowledge and performance on the children's mental transformation task. These findings might have important implications for early education, showing that supporting children's understanding of language might have an impact on their spatial reasoning.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	LITERATURE REVIEW	2
	The Relation Between Language and Thought	2
	Dimensional Adjectives	4
	Spatial Thinking	8
III.	MEASURE DEVELOPMENT	15
	Dimensional Adjective Selection	15
	Image Design	16
	Audio	17
	Touchscreen Measure	18
	Outcome Variables	20
IV.	STUDY 1: THE DEVELOPMENT OF DIMENSIONAL VOCABULARY IN SPANISH-ENGLISH BILINGUAL PRESCHOOLERS	22
	Background	22
	Aims	24
	Participants	25
	Materials	26
	Procedures	27
	Results	27
	Discussion	32
V.	STUDY 2: THE RELATION BETWEEN DIMENSIONAL ADJECTIVE COMPREHENSION AND SPATIAL SCALING	37
	Background	37
	Aims	37
	Method	38
	Results	40
	Discussion	43
VI.	STUDY 3: THE RELATION BETWEEN DIMENSIONAL ADJECTIVE COMPREHENSION AND MENTAL TRANSFORMATIONS	46
	Background	46
	Aims	46
	Participants	47
	Materials	47
	Results	47
	Discussion	49
VII.	CONCLUSIONS	52
	Introducing the Measures	52

Language Findings	53
The Spatial Scaling Study	53
Children's Mental Transformations	55
Implications	56
Future Directions.....	57
REFERENCES	59
APPENDICES	63
VITA	81

LIST OF TABLES

TABLE	PAGE
1. Pooled Means and Raw Minimum and Maximum Values, and Standard Deviation ...	63
2. Regression Model with General Vocabulary predicting English Dimension Terms	64
3. Regression Model with General Vocabulary predicting Spanish Dimension Terms ...	65
4. Regression Model with Spanish Dimension Terms and General Vocabulary predicting English Dimension Terms	66
5. Regression Model with English Dimension Terms and General Vocabulary predicting Spanish Dimension Terms	67
6. Pairs of Unmarked and Marked Terms Tested	68
7. English and Spanish Words from Most to Least Comprehended	69
8. Summary of Missing Values for Chapter V	70
9. Pooled Means and Raw Minimum and Maximum Values	71
10. Regression Model Predicting SST Score with Language	72
11. Regression Model Predicting SST Score with Reaction Time and Vocabulary.....	73
12. Regression Model Predicting SST Score with Concept Score and Controls	74
13. Pooled Means and Raw Minimum and Maximum Scores for Chapter IV	75
14. Regression Model Predicting CMTT Score with Dimension Terms	76
15. Regression Model Predicting CMTT Score with Dimensional and General Vocabulary	77

I. INTRODUCTION

A critical aspect of learning dimensional adjectives is the development of a conceptual understanding of a specific dimension, and the relational nature of variation along that dimension. While language is not necessary to have a concept, it likely is involved in most children's development of these concepts. Language helps to draw attention to specific aspects of our environment, with a clear causal link present between the words children hear and the words they in turn comprehend. Furthermore, there is growing evidence that language is closely related to spatial reasoning. Children who hear and produce more spatial language between 14- and 46-months out perform their peers on spatial reasoning tasks at 54 months (Pruden, Levine, & Huttenlocher, 2011). Additionally, adults who are allowed to use language perform better on a spatial reorientation task than those who complete the same task while doing a verbal overshadowing procedure (Hermer-Vazquez, Spelke, & Katsnelson, 1999). Bilingual children provide a unique opportunity to look at the link between language and thought. Lindholm, Padilla, and Romero (1979) found that bilingual children showed similar orders of relational word development in English and Spanish, with the exceptions being words that occur far less often in one language than the other. The current study aims to examine how children develop dimensional vocabularies, whether similar orders of acquisition are seen between English and Spanish, and whether children's comprehension of dimensional adjectives and knowledge of dimensional concepts relates to their performance on spatial thinking tasks. This dissertation will add to a growing literature on the relations between language and spatial reasoning, by exploring a specific type of spatial word (i.e., dimensional adjectives) in relation to a couple types of spatial thought.

II. LITERATURE REVIEW

The Relation Between Language and Thought

One long standing area of interest in language research has been the relation between language and thought. In the early twentieth century, work examining this relation was inspired by the general belief that European languages, with their orthography, were superior to languages without a written system (Kay & Kempton, 1984). Boas and his students argued by contrast that although languages might not have a written system, that they showed similar complexity and linguistic structures to European languages (Kay & Kempton, 1984). Student of Boas, Sapir, and Sapir's student Whorf, developed what is known as the Sapir-Whorf hypothesis. The critical hypothesis in the research of language and thought has two primary facets: first, that structural differences between languages are paralleled by cognitive differences in the speakers of those languages, and second, that a person's native language influences how he/she thinks (Brown, 1976). The Sapir-Whorf hypothesis has inspired decades of research in psychology and linguistics, trying to understand to what extent the language an individual speaks influences cognition, and to what extent cognition influences how language develops (e.g., Bowerman & Choi, 2003; Brown, 1976; Eilers, Oller, & Ellington, 1974; Gathercole, 1982; Klatzky, Clark, & Macken, 1973). One area of particular interest in determining the relation between language and thought are those terms that do not describe a concrete category, with clearly differentiated boundaries (Brown, 1976). While the way objects are labeled may vary between languages, much more variation is likely to be seen in fuzzy categories (i.e., categories without clearly demarcated boundaries) or in

relational terms (Brown, 1976). While two languages may share terms that can describe a certain concept, where that boundary is demarcated may not correspond across languages. For a speaker of two (or more) languages, these differences are often clear, as a thought in one language may not perfectly translate into the other language (Lenneberg & Roberts, 1955). To examine these ideas, clearly defined areas in research must be examined. Lenneberg and Roberts explored how colors were labeled cross-linguistically (Brown, 1976; Lenneberg & Roberts, 1955), however many other studies have chosen other categories to study, including relational terms (Clark, 1970; Gentner, 1978; Lindholm et al., 1979). Relational terms are an intriguing choice for understanding the relation between language and thought, because in order to understand a relational term, one must have a cognitive understanding of the relation between two or more things. For example, for an object to be tall, it must be measured from a zero point (e.g., the ground) upward, and must to some degree have more height than something else (Clark, 1970). It is not clear however, whether learning a term helps with the development of the relational concept, or whether having a concept leads to the comprehension of a term. The relationship between concept and term comprehension is complex, and likely not unidirectional, but by studying the development of relational terms in bilingual children, we might be able to understand to some degree how cognition and language interact in the development of relational concepts (Lindholm et al., 1979). The next section examines research to date on dimensional adjectives, including general research into the properties of dimensional adjectives, at what ages children learn these terms, and methods used to study the development of dimensional adjective vocabulary.

Dimensional Adjectives

From infancy, children learn words to label their world (e.g., Fernald, Perfors, & Marchman, 2006; Gampe, Liebal, & Tomasello, 2012; Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006). The earliest words children learn in English and Spanish are generally simple nouns (Gentner, 1978; Jackson-Maldonado, Thal, Marchman, Bates, & Gutierrez-Clellen, 1993). Words that describe abstract relations, such as the dimensions of objects, are more difficult to learn, and are first seen in children's vocabulary at a later age (Eilers et al., 1974). In English and Spanish, terms used to describe the size or relative size of objects are lexicalized in adjectives (e.g. *big*, *little*, *tall*, *short*, *grande*, *pequeño*, *alto*, *corto*). These terms do not describe an absolute size, but rather are inherently comparative. When compared to a mouse, a dog is big, but that same dog is little when compared to an elephant. Because of this relational nature, children must have a more complex conceptual knowledge to truly comprehend dimensional adjectives than is needed for most words.

Properties of Dimensional Adjectives. In both English and Spanish, many dimensional adjectives exist in pairs of polar opposites (e.g., *tall* and *short*; *alto* and *bajo*) (Klatzky et al., 1973). In these pairs, one term describes the marked or positive dimension, while the other describes the unmarked or negative dimension. The marked/positive term can be used in a neutral phrase to generally refer to the dimension, for example the question, "how *tall* is Sarah?" gives no impression of how tall Sarah is. However, using the unmarked/negative term intrinsically implies a dimension. The question, "How *short* is Annie?" implies that Annie is shorter than average. Research has previously found that children are likely to comprehend the unmarked term prior to the

marked term (Klatzky et al., 1973). The order of acquisition for dimension terms may be because in order to understand the marked dimension (e.g., *short*) the unmarked dimension (e.g., *tall*) must first be understood, because of the comparative nature of the marked term.

Although both English and Spanish encode dimensional information in adjectives, the languages have differences in the syntax used for adjectives. While in English, the adjective almost always comes before the noun (e.g. “the *tall* tree”), in Spanish, when using an adjective to distinguish an item you refer to, the adjective generally occurs after the noun (e.g. “el árbol *alto*”) (Stockwell, Bowen, & Martin, 1965). Bilingual children show cross-linguistic transfer, wherein they use noun-adjective orders for one language when speaking in the other language (e.g. Nicoladis, 2006; Nicoladis & Gavrilu, 2015;). Although word order may not have an influence on dimensional adjective comprehension, cross-linguistic transfer is clear evidence that bilingual children’s knowledge of adjectives is not entirely encapsulated within a language, but rather that children are transferring knowledge between languages.

Development of Dimensional Vocabulary. Previous findings suggest that when children first begin to comprehend dimensional adjectives they treat them as inflexible labels, such as calling a car big, but not labeling that same car as little when compared to a city bus (Sera & Smith, 1987). An understanding of the relative nature of these terms seems to appear in the later preschool years, with some errors still seen in the vocabularies of four- and five-year-old children (Sena & Smith, 1990). Interestingly, depending on the stimuli used, English speaking four- and five-year-old children can appear to perform less well than three-year-olds when asked to identify big and small

objects (Maratsos, 1973). Maratsos (1973) found that when two objects share a height, but have different widths, four- and five-year-olds label both objects “big”, while three-year-olds pick the objects with the wider width. However, Sena and Smith (1990) found that in a forced choice scenario, children will correctly choose the object with the greater width. Typically, the first words learned are those used to describe the overall size on all dimensions (e.g., big, little). Terms that describe size along a single dimension (e.g., long) are generally learned later, and there is some evidence that terms describing width are often late acquired (Bartlett, 1976).

The tendency for four- and five-year-old children to treat big similarly to tall does not appear to apply to all languages, with Arabic speaking four- and five-year-olds performing similarly to younger children (Gathercole, 1982). Gathercole (1982) proposes that these differences are semantic, rather than cognitive. That is, that the differences between how Arabic speaking and English speaking preschoolers is the result of differences in how the height dimension is encoded in their language. While the present dissertation does not focus on these differences, it is important to note that dimensional terms used to describe a concept in two languages may not have the same exact meaning. For example, in Spanish and Arabic the term used to describe *tall* can also describe *high*, while in English these concepts are lexicalized differently.

Although most of the research on dimensional adjectives has been conducted with monolingual children, Lindholm, Padilla, and Romero (1979) conducted a study looking at Spanish-English bilingual children’s comprehension of relational terms. While the focus of their study was separating out linguistic and cognitive influences on relational term comprehension, it provides some insight into how bilingual children’s acquisition of

dimension terms might unfold. The study found that, as with monolingual children, of the dimensional terms tested, those describing general size, like *big* and *little*, and *grande* and *pequeño* are learned before terms describing a specific dimension (e.g., *thick*, *thin*, *grueso*, *delgado*; Lindholm et al., 1979). Additionally, children showed similar order of acquisition across languages, with exceptions only where the frequency of use between the two languages varied greatly. Although Lindholm et al. (1979) answered many questions regarding bilingual language development, there are still questions left unanswered about the acquisition of dimension terms in bilingual children. Children's relative knowledge of each of their languages was determined through surveys distributed to parents and teachers, and was used only to determine a dominant language, rather than an overall vocabulary score. There may be non-linear relations between children's relative strength in each language and the acquisition of dimension terms, and also between children's overall language skill (e.g., receptive vocabulary) and their dimensional adjective comprehension. Finally, the methodology of the Lindholm et al. (1979) study, limited by the resources available in the 1970s, meant that children were tested using a set of cards, with the dimensions represented in white Styrofoam balls or in white paper rectangles. Each term was tested one time, allowing inferences only about comprehension at the group level, not individual differences. Additionally, the Mexican-American sample may not be reflective of learning in all young Spanish-English bilingual speakers as there could be differences in the specific words used and frequency of word use between Spanish speakers of different backgrounds. The current study aims to develop an easy to use, engaging, tablet game to test dimension terms in English and in Spanish.

Measures of Dimensional Adjectives. Although dimensional adjectives have been included on several measures of relational terms, including the Boehm Test of Basic Concepts and the Test of Relational Concepts, an established measure of children's knowledge of dimension terms does not currently exist (Boehm, 2000; Edmonston & Thane, 1992). Studies specifically on dimensional adjectives have created their own measures, generally using abstract shapes or line drawings (Bartlett, 1976; Eilers et al., 1974; Lindholm et al., 1979). To test children's receptive knowledge of dimensional adjectives a measure must be comparative. That is, it must force a child to compare the relative size of one or more images, as an object cannot be small unless it is smaller than something else. The importance of developing appropriate stimuli can be seen in the differences in the findings of Maratos (1973), and Sena and Smith (1990), where depending on the wording of the question asked of children, the same stimuli resulted in different responses. It is thus critically important that measures of dimensional adjectives be consistent in stimuli, script, and purpose, in order to understand not just when children comprehend these terms, but how knowledge of dimension terms might relate to cognition.

Spatial Thinking

Spatial thinking refers to a diverse set of skills, including the ability to navigate spaces, mentally rotate objects, use maps, and understand size, shape, location, and direction (Sinton, Bednarz, Gersmehl, & Uttal, 2013). The current study focuses on two specific spatial skills: the ability to mentally rotate and transform images and the ability to use scale maps to locate an item. Previous research has described a relation between children's early productive spatial vocabulary and their spatial thinking at 54 month

(Pruden et al., 2011). This section will review research findings on the development of mental rotation and transformation, spatial scaling, and the relation between spatial thinking and language.

Mental Rotation. While there are many aspects to spatial thinking, one of the most studied is mental rotation. Mental rotation is the ability to imagine rotating images in one's mind. Shepard and Metzler (1971) first studied the process in adults, by giving adults models of blocks to compare, some of which were identical and some which were mirror images. One reason why mental rotation has been so often studied is because it has a robust sex difference, where men consistently outperform women (e.g., Lachance & Mazzocco, 2006; Levine, Huttenlocher, Taylor, & Langrock, 1999; Parsons et al., 2004). As a developmental concept, however, it is important not only to look at sex differences, but to understand how all children develop the ability to rotate objects, and what factors might influence individual differences in performance.

To test children's ability to mental rotate and translate images (Levine et al., 1999) developed the Children's Mental Transformations Task (CMTT). Mental translation is a simpler skill than rotation, where one imagines moving images in one's mind, without turning them. While this skill is quite simple for adults, it is still challenging for young children. The CMTT includes 32 items. Each item consists of 2 target pieces, and a 2x2 array of choices. The array includes 1 image that can be made by putting the two target pieces together, as well as 3 foils, that are similar to the target, but have been altered so that they cannot be made from the target pieces. The types of images vary in a few ways. Sixteen of these images are unilaterally symmetric and 16 are bilaterally symmetric. In addition, there are four types of rotation and transformations;

there are horizontally translated targets, diagonally translated targets, horizontally rotated targets, and diagonally rotated targets. For all types of transformation, the targets are separated by 2cm at their closest points and rotation is 60°.

Levine et al. (1999) tested this measure on 280 children between 4 years and 6 years 11 months. Children were tested in six age groups, each of 6 months (e.g., 4 years to 4 years 5 months). Levine et al. (1999) were interested in looking at both age and sex effects on children's performance. They found a significant main effect for age, where the youngest two age groups (i.e., the 4-year-olds) were significantly lower in score than all the older groups. In addition, the third age group (5 years to 5 years 5 months) were better than all groups younger than them, and worse than all older groups. There were no significant differences between any of the three oldest groups. When testing the sex difference, the authors found that by 4 years 6 months there was a significant male advantage, which persisted through the older age groups. While this study clearly established that the measure is capable of testing shifts in children's mental rotation and translation ability, it does not address what factors might lead to individual differences in performance. While there are many possible factors that might lead to individual differences in performance, one important factor may be children's conceptual knowledge of dimensions. Children at these ages show great changes in their knowledge of dimensions, with some four- and five-year-olds making apparent errors in comparing the relative sizes of objects (Maratsos, 1973). A strong knowledge of dimensions is likely helpful in the comparison of the target pieces to the possible matches, as children with a stronger dimensional sense will have an advantage in comparing the edges of the pictures.

Spatial Scaling.

Another important spatial skill is the ability to use a map to find something. Map use requires several skills, including the ability to use a symbolic representation to understand the correspondence between items on the map and items in the real world, and the ability to change scale to compare a model with a larger space (Huttenlocher, Newcombe, & Vasilyeva, 1999). Huttenlocher et al. (1999) designed a task for 3- and 4-year-old children. Children were shown a map consisting of a rectangle drawn on a page. On that map, in one of four possible locations, there was a dot. The map corresponded to a rectangular sandbox where a small disk was hidden. Children had to use the maps to locate the hidden disk. Four-year-olds were very good at this, on average searching 3.5" from the target. However, 3-year-olds seemed to be in two groups, those who performed like 4-year-olds, and those who did not seem to use the map at all, and pointed indiscriminately. Unlike mental rotation abilities, there was no gender difference on this task. While this task began to address the development of map use, there was still a need for another task that could look at the importance of scale in the development of map use.

Frick and Newcombe (2012) established the Spatial Scaling Task as a test of children's developing scaling ability. Three-, four-, five-, and six-year-old children were tested, with 20 children tested per age. Children were tested either at their schools or in the lab. Children were told a story about Farmer Fred and his chickens. Children were shown pictures of the chicken hiding an egg, and were asked to show where the chicken hid the egg on a new page. Images were scaled with ratios of 1:1, 1:2, or 1:4. Additionally, some of the maps were narrow strips, some were rectangles, and some were circles. Children were asked to complete 25 trials. The distance between the actual

location, and the child's report of the location, was used as the dependent measure. An ANOVA looking at scaling factor (i.e., 1:1, 1:2, or 1:4), reference feature (i.e., strip, rectangle, or circle), age (i.e., 3-, 4-, 5-, or 6-years-old), and sex found a main effect of age. Post-hoc tests found differences between 3- and 4-year-olds, and between 4- and 5-year-olds, but not between 5- and 6-year-olds. These findings suggest that a critical time for the development of spatial scaling may be between 3- and 5-years-old.

Spatial Thinking and Language. An important contributing factor in the early development of spatial skill is likely children's experience with spatial language. Previous findings have found that language is important in adults' performance on spatial tasks (e.g., Hermer-Vazquez, Spelke, & Katsnelson, 1999; Ratliff & Newcombe, 2008; Shusterman, Ah Lee, & Spelke, 2011). Hermer-Vazquez et al. (1999) found that adults, who were given a spatial reorientation task, were unable to perform at typical adult levels when asked to engage in a verbal overshadowing task. In a spatial reorientation task an adult is placed in a small rectangular room with three walls of a neutral color, and one wall of a bright color. The participant watches as something is hidden in one corner. The participant is then disoriented, by being blindfolded and spun in circles. An adult should be able to use the geometric information of the room to determine two adjacent corners that the object might be hidden in (i.e., corners diagonally across from each other), and using the colored wall determine the exact corner. However, when adults engaged in the verbal overshadowing task, their performance dropped, suggesting that they were no longer using the colored wall to solve the task. The effect of verbal overshadowing may be because adults use language to help store this complex information (e.g., "the object is in the corner with the red wall to the left"). However, Ratliff and Newcombe (2008) have

suggested the effect of verbal overshadowing may be a result of cognitive load, rather than a critical role of language. The language used in instructions has also been found to impact both adults' and children's performance on a spatial reorientation task (Ratliff & Newcombe, 2008; Shusterman et al., 2011).

Pruden et al. (2011) examined the relations between children's expressive spatial language, parental language use, and children's spatial thinking outcomes. Parent-child dyads were observed in the home for 90-minute sessions every four months, from age 14 months to 46 months. These sessions were transcribed and coded for total parental speech, parental spatial tokens, total child speech, and child spatial tokens. For spatial language, the authors focused specifically on shape terms, dimension terms, and spatial feature terms. Dimension terms were frequently used at this age, with all children using the word "big" and 88% of children using the word "little." When the children were 54 months they participated in a battery of spatial tasks. The study found that children's performance on a spatial transformation task, a block design task, and a spatial analogies task were all correlated with the amount of spatial language the parents had used, as well as the amount of spatial language the child had used. Only the spatial transformations task was correlated with children's overall language use, and only spatial transformations and spatial analogies were correlated with parents' overall language use. The relation found by Pruden et al. (2011) implies there might be something special about the relationship between the spatial language children hear, and their performance on tasks, which require spatial skills. To understand the relationship between language and spatial reasoning better, we must first understand how children learn spatial language, and how they process spatial information at an early age.

The following chapters will describe the development of two new measures of dimensional adjective comprehension, the relation between dimensional vocabulary in Spanish and English in bilingual children, the relation between dimensional vocabulary and spatial scaling, and the relationship between dimensional vocabulary and mental transformations. The final chapter will discuss the findings of these three studies, and the conclusions we can draw from them.

III. MEASURE DEVELOPMENT

The following chapter outlines the steps taken to develop two touchscreen measures of dimensional adjective comprehension for preschool age children. Each measure tests the same terms, in English and Spanish respectively. Chapter III describes how the words used in the study were selected, how images were developed, the script and recording procedures for the audio stimuli, the programming of the tablet measure, and finally, the variables that the program will output. As a consequence of the parallel structure of the two measures, development is described simultaneously, with the end product of two separate programs that can be used to measure dimensional adjective comprehension in English, in Spanish, or if a child is tested on both, in English and Spanish.

Dimensional Adjective Selection

Words were selected from those used previously in studies of early adjective comprehension (e.g., Bartlett, 1976; Clark, 1970; Eilers, Oller, & Ellington, 1974; Huttenlocher & Higgins, 1971; Lindholm, Padilla, & Romero, 1979). Most Spanish and English terms were previously used in Lindholm et al.'s (1979) study of bilingual relational term comprehension. Since the previous study was conducted nearly 40 years ago, on a Mexican-American sample, adult native Spanish speakers were consulted to confirm that the Spanish terms were common equivalents to the English terms tested. These consultations led to us adding *enorme* and *chiquito* as alternative ways of describing large and small in Spanish. Bilingual adult speakers were all born out of the United States, and had all lived in Southern Florida for at least ten years. Their countries of origin included Argentina, Venezuela, and Guatemala. The terms tested in English are:

big, little, long, short, tall, short, large, small, fat, and skinny. The terms tested in Spanish are: *grande, pequeño, largo, corto, alto, corto, enorme, chiquito, gordo, and flaco*. These terms all are in pairs of polar opposites, with the unmarked term listed first. The concepts are in the same order for English and Spanish. While this list does not represent a comprehensive list of the dimension terms that young children may know, on the basis of previous research findings these terms should provide enough variability in comprehension to understand the development of these vocabularies, while including words that are easy enough that most three-year-olds should show some level of comprehension.

Image Design

The measure includes 40 test images (4 per dimension term). Each image depicts two drawings side-by-side of the same toy that have been altered to vary along the dimension of interest. Thus, each pair includes two images that represent the extremes of a specific dimension. For example, to test the comprehension of the dimensional adjective “short” two drawings, a short caterpillar and a long caterpillar were created and paired together in a side-by-side format (figure 1). The toys are displayed on a long table with one toy on the far-left side and one on the far-right side. Images were drawn in Adobe Photoshop CS5 Extended 12.0.2 X64 using photos of toys. Images were drawn by copying the outline and most important features of a toy using a black paintbrush tool. The outlines were then altered in size, by cutting out part of the outline, by separating the outline and adding additional space in the middle, or by altering the entire image in size. In a few cases, photos were taken of the same toy, with extra length or height added (e.g., a block tower was built and photographed in two heights), to serve as the model. After

the outlines were created, they were colorized. Bright and varied colors were used to make the task more interesting to young children who show a preference for novel images (Egan, Santos, & Bloom, 2007). The two images included all the same colors. After the color images were created, they were placed on the table template. Images were placed on the far left or far right thirds of the table, so that the marked image was on one side and the unmarked on the other side; side of image placement was counterbalanced such that in half of the images the marked dimension was presented on the right of the table and the other half of the images the marked dimension was presented on the left side of the table. In addition to the 40 test images, the measure includes eight practice images with two common items shown on either side of the table and an introductory image of a teddy bear in the center of the table (Figure 2), which will serve as the character children are asked to help. The practice images are an airplane, boat, car, book, cat, dog, bird, and horse. All these terms should be familiar in both Spanish and English by 36 months. Like images for test trials, all the practice items are toys, which have been drawn with a black outline, and colorized. The practice items are also shown on the left and right thirds of a long table (Figure 3).

Audio

Audio was recorded by a female bilingual speaker of Spanish and English. The speaker was a native speaker of both languages, who was born in Guatemala and raised in South Florida. The audio begins with a short story about a bear named Carla, who needs help finding the toys she wants to play with. After that, children hear audio asking, “Touch the x toy”, where “x” is the target dimension (e.g., for the caterpillar trial, a child would hear, “touch the *short* toy” or “toca el juguete *corto*”).

Touchscreen Measure

A touchscreen measure was chosen to provide a consistent testing experience that is intriguing to young children and provides recording both of response and response time. The touchscreen measure was developed using OpenSesame, an open source software for programming psychology studies (Mathôt, Schreij, & Theeuwes, 2012). Two versions of the touchscreen measure were made, one with accompanying Spanish audio, and one with accompanying English audio. The measures include two different sets of images for English and for Spanish, each with 40 unique toys. The measures consist of three sections: (1) an introduction to the measure; (2) eight practice items; and (3) 40 test items.

Introduction to the measure. In the introduction to the measure section, children are shown a teddy bear named “Carla” that needs help finding the toys she wants to play with. The purpose of the introduction is to explain to children what to do during the task, and to make the task more engaging by providing a storyline. Children are told, “This is Carla. Carla needs your help to find the toys she wants to play with. Will you help Carla? Touch the toys she asks for.” The introduction takes about 10 seconds, after which the practice trials begin automatically. The Spanish measure includes equivalent instructions, with the same bear “Carla” asking for help. The introduction is the only time the same image is used for Spanish and English, although the table toys appear on is consistent through all trials.

Practice items. During the practice items section, children view up to eight different practice items. For each practice item, they are shown images with two familiar objects on opposite sides of the table and hear the accompanying audio “touch the x” or

“toca el/la x.” These 8 practice items repeat in a random order until children answer three consecutive practice items correctly, at which point the test trials will immediately begin. Should a child not correctly answer three consecutive items even after these practice items have been repeated in a loop twice (16 trials total), testing will end, as this means the child is either unclear on the instructions, unfamiliar with very basic nouns, or is unwilling to respond.

Test items. The test items begin immediately upon a child reaching the correct item criterion from the practice items. During the test phase, children see images depicting two contrasting dimensional relations (i.e., one marked, one unmarked) while hearing accompanying audio, such as “*touch the short toy*” or “*toca el juguete corto.*” Children see the 40 test items in a random order seeing each of the 10 dimensional adjectives tested (i.e, English: *big, little, long, short, tall, short, large, small, fat, skinny*; Spanish: *grande, pequeño, largo, corto, alto, corto, enorme, chiquito, gordo, flaco*) four times. Different images are used in each trial, such that children see and are requested to find each dimensional relation four times (e.g., the *long* crayon, the *long* caterpillar, the *long* railroad, and the *long* baseball bat).

The measure is programmed to record touches to the left and right sides of the screen. Touches will only be recorded starting 1800 milliseconds into the audio. If a child attempts to respond before 1800 milliseconds pass nothing happens. As soon as the measure records a touch the next trial immediately begins. If a child does not respond 10,000 milliseconds (1 minute, 20 seconds) after the onset of the audio, then no response is recorded, and the next trial will begin.

Outcome Variables

For each trial, two variables are recorded: (1) *correct touch to the target dimensional relation*; and (2) *response time to make a decision on each trial*.

Using the variable *correct touch to target dimensional relation*, children's comprehension of each of the 10 dimensional adjectives in both English and Spanish is determined. For this measure a strict comprehension criterion is used, for which a child is said to comprehend the dimensional adjective if and only if they correctly touched the target dimensional relation on all four trials in which that dimensional relation had been tested. Trials in which a child did not respond within 10 seconds are considered incorrect trials. Thus, for each dimensional adjective term tested in both English and Spanish, children receive a binary score (1=comprehended term; 0 = did not comprehend term) reflecting that they either did or did not comprehend that term. Using these binary scores, a *total comprehension score* for both English and Spanish is calculated. The score has a maximum value of 10. The English *total comprehension score* (range = 0-10) and Spanish *total comprehension score* (range = 0-10) serve as the primary dependent variables. In addition, a *conceptual score* is calculated, for which children get a score of one for every concept they comprehend in at least one language; e.g., if a child understands *long* but not *largo*, they get a score of 1, and a child who understands *long* and *largo* also gets a score of 1. A child who understands neither *long* nor *largo* receives a score of 0 for that concept. Since there are four terms for one concept for *big*, *large*, *enorme*, and *grande*, and *little*, *small*, *chiquito*, and *pequeño*, the conceptual score has a range of 0-8. For these terms describing general size, children need to comprehend at

least one term for a score of 1, and receive a score of 0 if they comprehend none of the terms.

The *response time* variable is determined from the output of the program, which gives the number of milliseconds between the beginning of the trial and the recorded touch. A mean response time is calculated for all trials for comprehended terms, and for all trials for terms where a child missed at least one response.

IV. STUDY 1: THE DEVELOPMENT OF DIMENSIONAL VOCABULARY IN SPANISH-ENGLISH BILINGUAL PRESCHOOLERS

Background

Interest in the role of spatial language in early development has grown in recent years (Casasola, 2006; Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011; Pruden et al., 2011; Verdine, Bungler, Athanasopoulou, Golinkoff, & Hirsh-Pasek, 2017). These studies have looked at spatial language in many ways including children's expressive language use (Ferrara et al., 2011; Pruden et al., 2011), processing speed for shape terms (Verdine et al., 2017), and teaching children a novel spatial term (Casasola, 2006). However, the specific role of dimensional adjectives has been largely neglected in contemporary studies.

Dimensional adjectives are inherently relational, making them more difficult for young children to learn than terms that describe a concrete concept (Ryalls, 2000). For example, in learning the term tall, a young child might learn that a slide at the local park is tall, as it may indeed be quite tall in comparison to a child. But in comparison to a waterslide at an amusement park that slide would seem very short. When children first learn these terms, they may not use them in a comparative manner, rather treating dimension terms as fixed labels (Maratsos, 1973). A child in this stage would describe both slides as tall, not recognizing that in context the playground slide is short. In order to accurately assess children's comprehension of dimensional adjectives, it is thus critical that the objects tested not be ones where a child might already have assumptions about which dimension the object represents. Previous studies have primarily addressed this by presenting children with simple cardboard cutouts of various shapes, which vary in size,

or through simple line drawing, but we now can develop measures with complex stimuli that are salient to young children.

One understudied area of language development is the development of dimensional adjectives in bilingual children. Lindholm et al. (1979) conducted the only study to date looking at the development of dimensional adjective comprehension in a sample of bilingual early school-aged children. The children included in the study were Mexican-American children in California simultaneously learning English and Spanish. One limitation Lindholm et al. (1979) pointed out was that their stimuli might not be equally salient, with larger objects having higher salience. While larger objects being more salient is not something that can directly be addressed, a measure with generally more interesting stimuli might show less of this effect. Another limitation of the Lindholm et al. (1979) study is the focus on Mexican-American children, limiting the generalizability to the diverse Hispanic population in the US today. Between 1980 and 2010, the percentage of the US population identifying as Hispanic has increased from 6.4% to 16.3% (U.S. Census Bureau, 2012). It is increasingly important that we understand the development of Hispanic children, especially given that many Hispanic children are bilingual. The current study looks not only at children's knowledge of dimensional adjectives, using a new interactive measure, but also general vocabulary in English and Spanish, in a sample with diverse backgrounds.

The current study presents two new measures of dimensional adjective comprehension (one English and one Spanish), designed to assess the knowledge of bilingual children.

Aims

The current study aims to validate two new measures of dimensional vocabulary by describing the development of dimensional vocabulary in English-Spanish bilingual children between 36- and 72-months-old. Dimensional adjectives describe complex relations and may be representative of children's emergent ability to understand more relative terms, rather than terms describing concrete relations. The study has three specific aims.

Aim 1: To explore the relation between the number of dimension terms comprehended and general receptive vocabulary for both English and Spanish dimensional and general vocabulary. Aim 1 primarily serves to insure validity of the measure by establishing that we are in fact measuring an aspect of receptive vocabulary. The PPVT and TVIP (our measures of receptive vocabulary in English and Spanish respectively) are well established to be valid and reliable measures.

Hypothesis 1a: Children with larger than average general vocabularies in English will also have larger than average dimensional vocabularies in English.

Hypothesis 1b: Children with larger than average general vocabularies in Spanish will also have larger than average dimensional vocabularies in Spanish.

Hypothesis 1c: Children's general vocabulary in one language will not relate to the size of their dimensional vocabulary in the other language.

Aim 2: The second aim of this study is to ascertain whether children learn pairs of dimensional adjectives in a specific order. Previous work suggests that children learn the unmarked adjective first in a pair of dimension terms for both English and Spanish (e.g., Bartlett, 1976; Eilers et al., 1974; Lindholm et al., 1979). We will explore whether the

relation between unmarked and marked terms and order of acquisition holds true in a large sample, when many terms are tested.

Hypothesis 2: Children will be more likely to learn the unmarked dimensional adjective in a pair before the marked dimensional adjective, looking at within language pairs (e.g., children will learn *long* before *short*, and *largo* before *corto*).

Aim 3: The third aim is to explore how children's conceptual knowledge might influence their vocabulary across languages. That is, do children develop a concept of length that makes them more likely to learn dimensional adjectives that describe this concept in both English and Spanish (i.e., *long*, *short*, *largo*, *corto*). Additionally, this aim examines whether children will learn dimensional adjectives that describe a concept in the same order in English and in Spanish.

Hypothesis 3: When looking at group level data, the order of most comprehended to least comprehended terms will be similar between languages.

Participants

Ninety-two children participated in the study. Children ranged from 37.65- and 71.87-months-old (Mean=58 months). Forty-two children were male, and 50 were female. Most parents who completed the demographics questionnaire (N=46) reported that their children were Hispanic/Latino/Spanish (82%) and 91% reported their children were white (4.3% Black and 1.1% Other-Serbian, 1.1% Other-Mixed Asian and White). Family annual income varied greatly, with 9.5% of reporting families earning less than \$35,000 to 31% earning over \$100,000. Highest level of education for the parent completing the form included 13% graduate degree, 2.2% some graduate education, 43.5% Bachelor's degree, 17.4% Associates degree, 17.4% some college, 4.3% High

School Diploma or GED, and 2.2% less than high school. Since only 46 families reported highest parental education and 54 reported income these demographics should be considered cautiously.

Materials

Primary caregivers completed a consent form, and after their child completed at least one day of testing were given a demographics sheet including information about the family's socioeconomic status (i.e., income and education) and questions on family make-up and background. These forms were in paper format, and were distributed through the children's daycare centers.

Touchscreen measure. Both the Spanish and English touchscreen measures described in chapter III were used. Children participated in the task on a Samsung Galaxy Tab E Lite 7" Tablet while wearing volume limiting children's headphones. Each measure takes a maximum of 15 minutes to complete, although no child took this long.

General receptive vocabulary. Children's general receptive vocabulary skill was tested in English and Spanish using the PPVT and TVIP, respectively.

Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4). The PPVT-4 is a standardized measure of English receptive vocabulary, normed for ages 2 years 6 months through 90 years (Dunn & Dunn, 2007). The test takes less than 20 minutes for most participants. Four images are displayed on a page, and participants are asked to point to an image depicting a specific word. The PPVT provides standardized scores with a mean of 100 and standard deviation of 15. These scores are normed by age, so scores from a 3-year-old are comparable to scores from a 5-year-old.

Test de Vocabulario en Imágenes Peabody (TVIP). The TVIP is a standardized measure of Spanish receptive vocabulary, normed for ages 2 years 6 months through 18 years. It is similar in length to the PPVT-4 taking about 20 minutes to administer, and like the PPVT-4 consists of four images displayed on a page, where participants are asked to point to an image depicting a specific word. Like the PPVT, the TVIP will give each child a standardized score, based on their age, with a mean of 100 and standard deviation of 15.

Procedures

Each child was tested over two days. On the first day of testing children were tested on both English measures, and on the second day of testing children were tested on both Spanish measures. On each day of testing children were taken to a quiet area in their classroom or in another room in the school, usually an empty classroom, although at one school children were tested outside. They first completed the touchscreen measure. After completing the touchscreen measure children completed the PPVT or TVIP (depending on the day of testing). Children were also tested on spatial measures, but these measures are not included in this study (see chapters V and VI). Children were given a sticker for participation after each day of testing even if the child did not complete any or all assessments.

Results

This study aimed to understand the relation between children's comprehension of dimensional adjectives in English and Spanish. Specifically, the study was designed to understand whether children's comprehension of dimensional adjectives in English and Spanish is related beyond their general language knowledge, whether children are more

likely to learn the unmarked adjective before the marked adjective in a pair, and whether bilingual children learn concepts in a similar order across language.

Multiple Imputations. While most children completed all tests, there were children who were not tested for every measure. The data appear missing completely at random based on Little's Test, with 2.2% missing for the PPVT, 31.5% for the TVIP, 1.1% for the English Dimension Task, and 15.2% for the Spanish Dimension Task. The much higher levels of missing data for the Spanish measures is because of children missing the second day of testing after completing the first. Other causes of missing data include children not wanting to complete the measure, equipment malfunction, experimenter error, or children failing to score high enough to receive a standardized score on the PPVT or TVIP. To address these missing data in as unbiased a manner as possible, multiple imputation was utilized. Multiple imputation estimates missing values using children's scores on other variables and scores of other children in the sample, to create complete datasets. To account for variations in scores associated with unmeasured factors, several datasets are created with imputed scores. Multiple imputation has been shown to provide relatively unbiased results (Schafer & Graham, 2002). For the current study, imputations were run using the "mice" package in R version 3.4.2 "Short Summer". Predictive mean matching (pmm) was used, with 50 maximum iterations, and 10 imputations. Results presented below used this imputed dataset.

Descriptive Statistics. The primary variables of interest in this chapter are PPVT (*Mean*=95.54), TVIP (*Mean*=85.92), age (*Mean*=57.90 months), English dimensional vocabulary (*Mean*=3.71), and Spanish dimensional vocabulary (*Mean*=3.32). See Table 1 for the range and standard deviation based on the raw values.

We also calculated language dominance for both general vocabulary and dimensional vocabulary, by subtracting Spanish scores from English scores, where negative scores represent Spanish dominance, positive scores English dominance, and scores of zero perfect balance. For general vocabulary 39 children were Spanish dominant, 52 were English dominant, and one was balanced. For dimensional vocabulary 36 children were Spanish dominant, 42 were English dominant, and 14 were balanced.

Dimension Terms and General Vocabulary. The first aim of the study was to examine the relation between the development of dimensional vocabulary in English and Spanish. The first aim was further broken down into three hypotheses, 1) that children with larger general vocabularies in English would have larger dimensional vocabularies in English, 2) that children with larger general vocabularies in Spanish would have larger dimensional vocabularies in Spanish, and 3) that children's general vocabulary in one language would not predict their dimensional vocabulary in the other language. Analyses exploring these hypotheses are presented below.

The relation between English general vocabulary and English dimensional adjective knowledge. A linear regression model was run to determine whether English general vocabulary (PPVT) is predictive of children's performance on the English dimensional vocabulary test. Age was included as a control variable since PPVT was standardized. The analysis found that age ($B=.125, p<.001$) and PPVT ($B=.039, p=.009$) were both significant predictors of English dimensional vocabulary, with a constant of -7.298.

The relation between Spanish general vocabulary and Spanish dimensional adjective knowledge. To examine the predictive power of general vocabulary (TVIP) for

dimensional adjective comprehension, we ran a linear regression including age as a control variable. The analysis found that TVIP ($B=.038$, $p=.014$) and age ($B=.116$, $p<.001$) were both significant predictors of Spanish dimensional vocabulary (constant=-6.674).

Cross-language predictive power of general vocabulary on dimensional adjective knowledge. Hypotheses 1a and 1b focus on the role of general vocabulary as a predictor of dimensional adjective vocabulary within language. Hypothesis 1c states that general vocabulary in one language will not be significant predictor of dimensional adjective comprehension in the other language. To test hypothesis 1c, each model was run twice, with each English dimensional vocabulary and Spanish dimensional vocabulary as the dependent variable. Like the models looking at a single language, these analyses all include age as a control variable. First, the most basic model includes both general vocabulary measures (i.e., PPVT and TVIP) and age as predictors of dimensional vocabulary (see Table 2 for English and Table 3 for Spanish). Both measures find that general vocabulary and age are significant predictors of dimensional vocabulary within language, but that general vocabulary in the other language is not a significant predictor.

Additionally, we were interested in whether knowledge of dimension terms in one language could predict knowledge of dimension terms in the other language, even though general vocabulary did not. To examine this, regression models were again run, this time with dimensional vocabulary in the other language as an additional predictor. To examine both English and Spanish, two models were run, one with English dimensional knowledge as the dependent variable and age, PPVT, TVIP, and Spanish dimensional knowledge as predictors (Table 4), and the other with Spanish dimensional knowledge as

the dependent variable and age, PPVT, TVIP, and English dimensional knowledge as predictors (Table 5). These models found that general vocabulary within language and age were consistently significant predictors, but that there was not cross-language prediction either from general vocabulary or dimensional vocabulary.

Comparing Unmarked and Marked Adjectives. The second goal in this chapter is to explore the hypothesis that children learn the unmarked term before the marked term within pairs of dimensional adjectives (e.g., tall learned before short). To test the hypothesis, we looked at cases where a child comprehended only one term within a pair of dimensional adjectives, disregarding any cases where a child either comprehended both the unmarked and marked term, or did not yet comprehend either term (see Table 6 for a list of the pairs tested). A binomial probability test was run to determine whether there were significantly more children who knew the unmarked and not the marked (UM/M) than who knew the marked and not the unmarked (M/UM). Spanish and English pairs were tested separately. In English, there were 97 UM/M pairs (66%) and 47 M/UM pairs (34%) in the raw data, and 92.3 UM/M pairs (65%) and 48.7 M/UM pairs (35%) pooled across the imputations. The raw data and all 10 imputed data sets showed that this was significantly different from a change rate of 50% ($p < .01$ for all tests). The Spanish results reflect a similar pattern, with 95 UM/M pairs (67%) and 47 M/UM pairs (33%) in the raw data, and 110.7 UM/M pairs (64%) and 62.3 M/UM pairs (36%) pooled across the imputations. The raw data and all 10 imputed data sets showed that this was significantly different from a change rate of 50% ($p < .05$ for all tests).

Order of Term Comprehension Between Languages. Our final aim for this study was to look at whether children learn terms in a similar order across the two

languages. To explore the question, the percent of children who comprehended each word was examined, to see if the most understood and least understood words were the same in Spanish and in English. Tall and small were the most comprehended English words, and alto and grande were most comprehended in Spanish, while fat and skinny were the least comprehended in English and corto (length) and gordo were least comprehended in Spanish (see Table 7 for full lists of comprehension). Although the two languages had the same most comprehended term, the order diverged after the first concept.

Discussion

The current study examined the progression of dimensional adjective learning in bilingual preschool aged children. Specifically, this study looked at predictors of how many dimensional adjectives a child might comprehend in each language, whether children learn the unmarked term before the marked within a pair of polar opposite dimensions, and, finally, at the order in which children learn dimension terms.

All children in the study were tested on general vocabulary and dimensional adjective knowledge in both Spanish and English (see “Multiple Imputations” above for exceptions). We found that children’s general vocabulary in a language was a predictor of their knowledge of dimension terms within language for both Spanish and English, where children with larger general vocabularies knew more dimension terms. The relation between dimensional vocabulary and general vocabulary is unsurprising, since learning dimension terms likely relies primarily on the same mechanisms as other parts of vocabulary, but provides evidence of convergent validity, an important gauge for a new measure.

We also looked at the role that one language might have on knowledge of dimension terms in the other language. We did not find cross-language prediction, with neither general Spanish vocabulary nor Spanish dimensional vocabulary predicting English dimensional vocabulary, and with neither general English vocabulary nor English dimensional vocabulary predicting Spanish dimensional vocabulary. While previous studies have not looked specifically at whether knowledge of dimensional vocabulary might be related across language in bilingual children, other work looking at bilingual children has found that vocabulary and some skills such as processing speed are not related between languages (Marchman, Fernald, & Hurtado, 2010). There is also the possibility that there is a relation between dimensional adjective learning in Spanish and English that this study was unable to determine. One hypothesis is that children who have learned a label for a concept in one language would have an easier time learning a label for that same concept in their other language; for example a child who knows what tall means would have an easier time learning alto. However, to test order of acquisition one would need to study children's acquisition of dimensional adjectives in a longitudinal study or an experimental study. Future research should examine these options, as it would provide strong evidence of the importance of conceptual knowledge in the learning of dimensional adjectives.

As mentioned in the literature review, previous research looking at dimensional adjective comprehension in young children posits that children will learn the unmarked term before the marked within a pair of dimensional adjectives. While our study design did not allow us to determine the order in which words were learned when a child understood both terms in a pair, we were able to look at cases where a child knew only

one word within a pair to determine whether they were more likely to know the unmarked and not the marked than to know the marked and not the unmarked. We found that for both Spanish and English there were significantly more cases where children knew only the unmarked than cases where children knew only the marked than would be expected by chance. While this pattern did not hold for 100% of trials, there are several factors that may contribute to variation in the order children learn terms. First, several terms have multiple possible opposites. For the case of *big/large* and *little/small* and the Spanish terms *grande/enorme* and *pequeño/chiquito* multiple terms were tested, but only the primary pairs were included in this analysis. Additionally, several of the pairs tested could be matched with other words. For example, in English, *thin* could be used as the opposite of *fat*, or in Spanish *bajo* might be used to describe someone who is not tall. In these cases, a child might appear to only comprehend half of a pair, when in fact that child comprehends both an unmarked and marked term to describe that dimension.

We were also interested in whether children would show similar orders of word acquisition between languages. Since it is impossible to know the order individual children learned these words, we instead looked at the percent of children tested who comprehended each word. While *tall* is the most comprehended word for both English and Spanish, the word order diverges after that. The outcome of the current study is contrary to that of Lindholm et al. (1979), who found that with a few exceptions children showed a similar order of acquisition between Spanish and English. Lindholm et al. (1979) suggest that the differences between the languages could be attributable to differences in the frequency of word use between Spanish and English. Additionally, there is likely a difference in frequency of word use between Spanish speakers from

different backgrounds, which Lindholm et al. (1979) did not have to address as their sample was solely Mexican-American children. While no study has specifically addressed this question from a developmental standpoint, research has looked simply at frequency of word use in native Spanish speakers. For example, in a study looking at the use of *ser* and *estar*, verbs in Spanish that both translate to *to be* in English, Malaver (2012) found different rates of use for *chiquito* and *pequeño* depending on the country, with Mexican speakers using *chiquito* more often than *pequeño* and Guatemalan speakers using *pequeño* more often than *chiquito*. This reflects what native Spanish speakers told us in the measure design phase described in chapter III. Additionally, there may be within language differences in which dimension terms are most frequently used, even when there is not an overlap in meaning.

The main goal of the study was to explore the nature of dimensional adjective learning in bilingual preschool aged children. Using a novel tablet measure we were able to collect more trials than previous research on dimensional adjectives and to use more complex stimuli. We found that children with larger general vocabularies in a language knew more dimension terms in that language, providing convergent validity. By contrast, no effect of either general or dimensional vocabulary in Spanish was found for English dimensional vocabulary, and no effect of either general or dimensional vocabulary in English was found for Spanish dimensional vocabulary. In our second goal, we found that children were significantly more likely to know only the unmarked term within a pair than only the marked term, supporting our hypothesis that unmarked terms are learned before marked. Finally, we looked at the order children learned terms, finding different patterns between the languages. There are likely many factors that determine what order

words are learned, and future research should explore this in bilingual children in a longitudinal framework. Overall, the results from the current study show the importance of looking at both languages spoken by bilingual children in order to understand their comprehension of dimensional concepts.

V. STUDY 2: THE RELATION BETWEEN DIMENSIONAL ADJECTIVE COMPREHENSION AND SPATIAL SCALING

Background

We use spatial skills every day in tasks as simple as deciding how big a container to use for leftover pasta, to the complex engineering that sent us to space. Given the importance of these skills across development, but especially for science, technology, engineering and mathematics (STEM), it is critical that we understand early development of spatial skills. There are likely many factors involved in early spatial development, but one exciting factor is the role of spatial language, that is language describing qualities including size, shape, location, or direction, has on the development of spatial reasoning. Pruden et al. (2011) found that children's use of spatial terms describing spatial properties and features of objects or people in toddlerhood and early childhood was predictive of their performance on spatial reasoning tasks at four and a half. Additionally, Verdine et al. (2017) found that how quickly children identified shapes at three was predictive of their later spatial reasoning skill. The current study looks at whether dimensional adjectives predict children's performance on spatial scaling, a spatial reasoning task that requires a strong comprehension of relative distance.

Aims

The primary aim of this section is to understand the relation between receptive dimensional adjective vocabulary and early spatial scaling skill. Previous research has found a relation between children's early productive spatial vocabulary and their spatial reasoning skill, specifically mental transformations, and spatial analogies (Pruden et al.,

2011). The current study aims to explore whether the same relation is true specifically with dimensional adjectives (a subset of spatial language) and of receptive, rather than expressive vocabulary. Additionally, rather than looking at mental transformations and spatial analogies this chapter focuses on children's ability to spatially scale (see chapter VI for an examination of mental transformation). We expect that children who have a strong conceptual knowledge of dimensions will outperform their peers with a weaker conceptual knowledge of dimension on spatial scaling tasks, as these children likely have a stronger understanding of size and distance, critical skills in spatial scaling.

Aim 1: This study examines whether children's early knowledge of dimensions relates to performance on the Spatial Scaling Task (SST; Frick & Newcombe, 2012).

Hypothesis 1: Children who know more dimensional concepts will have smaller deviations from the target in the SST.

Method

Participants. The same participants from study 1 participated in this study. In total 92 children between 37.65 and 71.87-months-old (M=58 months) participated in the study. For more information on the make-up of the sample see chapter IV.

Materials. Materials were the same as those for the study in chapter IV, with the addition of the Spatial Scaling Test (SST; Frick & Newcombe, 2012).

SST. The SST is a non-verbal spatial task, appropriate for ages 36-81 months. The SST measures children's ability to use a model to determine the location of a "hidden" object. Children were presented with a story in English about Farmer Fred and his chickens, which hide their eggs. Children were then shown pictures of the chickens hiding eggs. They were then asked to point on a new picture to where the egg was

hidden; this image was 4 times the size of the model image. The field shown varied in shape, with narrow strips, rectangles, or circles used. In total children were shown 24 trials. Scores were determined by mm deviations from the correct location, with the total score as a mean of the deviations for the 24 trials.

Procedures. Testing for each child took place over two days within two weeks of each other. On the first day of testing, children were tested on the English language measures (i.e. PPVT and tablet measure) and the SST. On the second day children were tested on the TVIP and tablet measure in Spanish. On each day of testing children received a sticker of their choice at the end of testing, regardless of whether the child completed all assessments. Children were tested in a quiet space in their classroom or school.

Variable Scoring. This study included five measures, the PPVT, TVIP, SST, and the dimension task in English and in Spanish. The PPVT and TVIP are both standardized measures, and were scored per the measure standards. The scores used were scaled by age.

The Spatial Scaling Test was scored by measuring the distance between the actual location of the egg, and the child's estimate. For children who responded around the periphery of the field, the furthest possible distance within the field was assigned. If a child refused to respond or the experimenter failed to record the child's response, no score was given for that item.

Two ways of scoring the dimension measures were used for this study. The first is comprehension by language. For this score children were considered to comprehend a term if they answered correctly for all four trials of that word. The score was thus a

simple count of words comprehended in that language, resulting in two scores, one for Spanish dimension term comprehension and one for English dimension term comprehension. These scores both range from 0-10. The other way of scoring these measures for this study was a measure of concept comprehension across language. These concept scores were calculated by looking at the two words, or for general size four words, representing this concept across the two languages. If a child comprehended at least one term for a concept, whether in Spanish or English, the child received a score of one for that concept, while children who did not know any word tested for that concept received a score of zero.

Results

The primary aim of this study was to determine whether children's knowledge of dimensions is predictive of their performance on the SST. This section presents descriptive statistics for the SST, and several models to predict children's performance on the SST based on their knowledge of dimension terms and other potential confounding variables.

Multiple Imputations. To address missing data in as unbiased a manner as possible, multiple imputations were run using the variables included in the analyses in this section, including continuous demographic variables, spatial scaling test item scores, comprehension for each dimension term, PPVT, TVIP, and age. Imputations were run using R version 3.4.2 "Short Summer" using the "mice" package. Predictive mean matching (pmm) was used, with 50 maximum iterations, and 10 imputations. All subsequent results in this section were run using this dataset, and unless otherwise noted results provided are pooled results based on the 10 imputed datasets, run using SPSS

version 20 or version 23. For a summary of missing values see Table 8. Note that missing values on the SST are given at the item level as participants could refuse to respond to some but not all items, and in some cases the experimenter failed to record one or two responses from a participant. For the PPVT, TVIP, and the two tablet measures participants either have the entire measure missing or completed all items so missingness is described at the assessment level.

Descriptive Statistics. Table 9 contains the pooled means for each item on the SST, as well as the PPVT, TVIP, and the mean score for the SST. Minimum and maximum values are based on the raw data, since there is not a convention for pooling these values. For the individual items on the SST the maximum value represents the highest possible score for each item, as at least one child marked off the field for each item. While several items do not have a minimum score of 0, the highest minimum value for an item is only a deviation of 8mm.

Predicting SST Score. The primary aim of this study was to establish whether knowledge of dimensional adjectives predicts children's skill at spatial scaling. A series of regressions are presented here determining the role of dimensional adjective vocabulary in Spanish and English in predicting SST score. Note that smaller scores on the SST represent higher skill, so we expect a negative relation between dimensional vocabulary and SST score. The most basic model including only Spanish dimensional vocabulary and English dimensional vocabulary found that English was a significant predictor ($B=-4.971$, $p<.001$), but Spanish dimensional vocabulary was not ($B=.430$, $p=.696$), with a constant of 64.34. To establish that the relation between English dimensional vocabulary can be explained beyond just representing children with better

language skills PPVT, TVIP, and age were all added as control variables. This model, which is presented in full in Table 10, found that English dimensional vocabulary, PPVT, and age are all significant predictors of SST score, while neither TVIP nor Spanish dimensional vocabulary are. Additionally, we were interested in how reaction time might be related, and ran a regression including English dimensional vocabulary, Spanish dimensional vocabulary, reaction time (RT) on comprehended English terms, RT on comprehended Spanish terms, RT on English terms not comprehended, and RT on Spanish terms not comprehended (Table 11).

In addition to looking at comprehension in each language as predictors of SST score, we were interested in whether comprehension of concepts (e.g., tall) would predict children's performance, whether in English or Spanish (e.g., understanding either alto or tall). A score for number of concepts comprehended was calculated per child, with a lowest minimum score of 0 and highest score of 8 (the highest possible). The mean score was 4.36, a score very close to the middle of the range. A regression with English dimensional vocabulary and Spanish dimensional vocabulary regressed on Concept Score found that English ($B=.497, p<.001$) and Spanish ($B=.463, p<.001$) showed similar strength as predictors of Concept Score.

Concept score proved a powerful predictor of SST score. In a basic model, we found that concept score was a significant predictor of SST score ($B=-5.293, p<.001$) with a constant of 67.508. It remained significant with PPVT, TVIP, and age added as control variables (Table 12).

Discussion

The primary aim of goal of the current study was to explore the relation between children's emerging dimensional vocabularies and their ability to spatially scale. The results of this study suggest that children's knowledge of language describing the sizes of things predicts their ability to estimate location in a scale model. Children were tested on two measures of dimensional adjectives, one in Spanish and one in English. These measures covered the same concepts across language, such that children were tested on the word *tall* in the English measure, and its Spanish correlate *alto*. To examine children's understanding of dimensional concepts, rather than their vocabularies in each language, this study looked at whether a child understood a term describing a concept in either Spanish or English (e.g., a child would get credit for the concept *tall*, if he/she comprehended *tall* or *alto*, or both words). Using this criterion, a child who understood at least one word describing a concept was given a positive score for that concept, for scores ranging from 0-8. Children in this study also participated in a spatial scaling task, where they had to find a spot on a map where an egg was hidden based on a small scale model. Scores were based on how accurate children were, with a primary measure of average millimeter deviations from the correct locations. We found that children who knew more dimensional concepts showed lower average deviations on the scaling task. While age and general vocabulary in English also are significant predictors in this model, we see here a role of dimensional concepts beyond that of stronger language skill. We propose that this relation represents a stronger understanding of relative size, which is critical both for dimensional vocabulary and for accurate scaling estimates. These results are in line with previous research on the relation between spatial language and spatial thinking such

as Pruden et al. (2011), which found that the more spatial words children used the better they performed on spatial reasoning tasks at four and a half. Our study looked at a specific type of spatial language, dimensional adjectives. Additionally, the current study explored comprehension, rather than production. Our findings, in conjunction with Pruden et al.'s findings, support the view that early spatial language ability might be an important predictor of the development of spatial reasoning. Given the importance of spatial reasoning in math performance and other STEM domains, we believe that it is critical to continue to look into the role of spatial language in early development. The next step following the research presented here is an intervention study, to see if learning dimension terms helps improve scaling ability.

The current study had some limitations. Children were only tested on the spatial scaling test in English, the language the test was developed in. In addition, they were only tested in English on the other tests given that day. This may have primed children to think about these questions in English, which might have contributed to the stronger relation seen between English dimension terms and SST score (see Table 10 for an analysis including English and Spanish). There may also have been children who did not understand the instructions given for the task due to weaker English language skill. These children may have understood the minimum, that we expected them to point somewhere on the field, but not that there was a relation between where the egg was on the map and where they were expected to point on the field. Future research should adapt the scaling test to be given in Spanish, so children could be tested in the language they are stronger in. The relation between relative strength in each language, and overall vocabulary in each language, adds a layer of complexity to the interpretation of these analyses. That is,

that a child who has a low vocabulary score in Spanish might be a child whose primary language is English, or a child who just has a relatively small vocabulary overall, but is balanced between languages or is stronger in Spanish. A longitudinal study could better address these complexities, by looking at language development over time to model non-linear patterns, and how the growth in dimensional language might predict the development of spatial scaling skill.

The central aim of this study was to determine that children's comprehension of dimensional adjectives relates to their ability on a spatial scaling task. This relation held when controlled for by age and children's general vocabulary skill in English and Spanish. These findings lend support to the hypothesis that spatial language is critical in early spatial reasoning development (e.g., Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011; Pruden et al., 2011). This study was the first to look at how dimensional adjectives specifically relate to a spatial reasoning skill. Future research should look at this relation from a longitudinal standpoint, to see how spatial language and spatial reasoning develop concurrently.

V. STUDY 3: THE RELATION BETWEEN DIMENSIONAL ADJECTIVE COMPREHENSION AND MENTAL TRANSFORMATIONS

Background

One area of spatial reasoning that has long been of interest is mental rotation, or the ability to imagine objects turning in one's mind (e.g., Estes, 1998; Hegarty, 2017; Levine et al., 1999). In young children, the Children's Mental Transformation Task (CMTT) assesses the ability of children as young as four to mental rotate and translate objects (turn objects, and move pieces together; Levine et al., 1999). In their 2011 study, Pruden et al. linked performance on this task to early use of spatial language describing the spatial qualities of objects or people (i.e. size, shape, spatial features). The present study examines whether there is a link between concurrent receptive knowledge of dimensional terms and children's performance on the CMTT.

Aims

This section explores the relation between children's comprehension of dimensional adjectives and their mental transformation skill. Pruden et al. (2011) found that children with larger productive spatial vocabularies performed better on a mental transformation task at 54 months. This chapter looks more closely at a specific type of spatial language, dimensional adjectives, and whether children's comprehension of these terms relates to their performance on the Children's Mental Transformation Task, the same task used by Pruden et al. (2011).

Aim 1: This study aims to determine whether children's early knowledge of dimensions relates to their performance on a mental rotation and transformation task.

Hypothesis 1: Children with larger conceptual scores will perform better on the Children's Mental Transformation Task (CMTT; Levine et al., 1999), a measure of mental rotation and transformation.

Participants

A subset of the sample from chapter II and III participated in this study. A sample of 79 48-72-month-old Spanish-English bilingual children (39 female), with an average age of 60.5 months, were recruited from preschools in Miami-Dade County for this study. All children who participated in the larger study were eligible to participate in this study if they had reached their fourth birthday by the time of testing. Three-year-old children were excluded due to the difficulty of the task for younger children.

Materials

Materials were the same as those for the study in chapter IV, with the addition of the Children's Mental Transformations Task (CMTT).

CMTT. The CMTT is a measure of children's mental rotation and transformation abilities. It is a non-verbal spatial task, appropriate for ages 48-83 months. The measure includes 32 items. Each item consists of a sample image and four possible matches. The sample image is two pieces, that when put together, or when put together and rotated, make up one of the four matches. Children are asked, "*Look at these pieces, now look at these shapes. If you put the pieces together they will make one of the shapes. Point to the shape the pieces make.*" Scores are the number of correct items.

Results

The primary aim of this study was to explore whether children's comprehension of terms describing dimensional concepts relates to their performance on the CMTT. The

following section includes a description of missing data procedures, descriptive statistics, and models of the relation between dimensional adjective comprehension and CMTT.

Multiple imputations. Due to several factors, including experimenter error, equipment error, children’s unwillingness to be tested, and school absences on one of the testing days, there were many missing values within the dataset (see table 6 for more detail). Multiple imputation offers an approach to missing data that reduces bias in subsequent analyses. The “mice” package in R version 3.4.2 “Short Summer” was used to run imputations. Predictive mean matching (pmm) was used, with 50 maximum iterations, and 10 imputations. All analyses presented in this chapter were run on imputed data unless otherwise noted, and pooled results from 10 imputed datasets are presented.

Descriptive Statistics. Means from the pooled imputations and raw minimum and maximum scores are presented in Table 12 for CMTT, PPVT, TVIP, age, English dimension terms, and Spanish dimension terms.

Predicting CMTT. The goal of this chapter was to establish whether children’s knowledge of dimensional adjectives in English and Spanish is related to their performance on a mental rotation and transformation task. Since age is strongly correlated with all three measures, it is included as a control variable in all analyses. The first model included three predictors of CMTT score: English dimensional vocabulary, Spanish dimensional vocabulary, and age. Results are summarized in Table 14. An additional regression was run adding PPVT and TVIP as predictors (Table 15). Given the lack of results in these analyses, no subsequent analyses were run.

Discussion

The study did not detect any evidence for a link between dimensional adjective comprehension and children's mental rotation and transformation skill. While Pruden et al. (2011) found that spatial language production was related to CMTT scores, there are several explanations for why the current study might have found different results. Three explanations that will be offered below focus on how dimensional adjectives might be different from general spatial vocabulary, potential differences in receptive and expressive language, and the possibility of differences in age at testing.

CMTT is unrelated to size knowledge. The first explanation as to why we did not find a relation between CMTT and dimensional vocabulary is that understanding size does not relate to skill on CMTT. The CMTT requires a child to look at two pieces that make up a shape, and determine which of four shapes those pieces make. All shapes are controlled for size, so dimension is likely not that useful a tool for this task. Given this, a child with a strong understanding of dimensions would not be more likely to succeed on this task than a child with a similar vocabulary but weaker knowledge of dimension terms. Pruden et al.'s (2011) finding might rather be attributed to children's knowledge of shapes, another type of spatial language included in their study.

Receptive language might be different from expressive. It is also possible that there is a stronger link between expressive vocabulary and CMTT score than receptive vocabulary. It is possible that our children showed comprehension for words on the receptive task that they did not yet possess in their expressive vocabularies. These children might not be confident enough with those words to use them in narrating the task in their mind, which Hermer-Vazquez et al. (1999) suggest might be important in certain

spatial reasoning tasks. This hypothesis is likely the weakest explanation here, but the most easily ruled out, simply by testing children's receptive and expressive dimensional vocabulary, and their scores on the CMTT.

Early word learning hypothesis. The final hypothesis is that children who learn more dimensional terms early in childhood, have an advantage by age four. Pruden et al. (2011) recorded language samples from 14-46 months, and tested CMTT at 54 months, while our study tested language and CMTT concurrently. This leads to a possible explanation that the discrepant results may be due to age. That is, perhaps children who master spatial terms at a younger age have an advantage in spatial reasoning tasks over those who learn these terms later. Verdine et al. (2017) found that speed at identifying shape terms at 3 years predicted later spatial skill, but did not predict concurrent spatial skill, lending support to this hypothesis. If dimensional adjective comprehension shows nonlinear growth, where children who learned the terms later could catch up to their early learning peers, we might be missing an effect of growth, seen by Pruden et al. (2011). A longitudinal study looking at the growth of dimensional vocabulary would address this hypothesis.

Conclusions. Although it is difficult to draw conclusions from null results, especially given the concern that lack of statistical power and considerable confounding variables could be hiding a real effect, in this study there are a number of strong explanations for why children's receptive understanding of dimension terms might not be related to their mental rotation and translation skills, even though general expressive spatial language has previously been shown to be related (Pruden et al., 2011). Three hypotheses, presented above, propose that spatial terms other than dimension terms (e.g.,

shape terms) might be stronger predictors of CMTT score, that expressive language might be more related to CMTT than receptive language, or that the age at which a child learns a term might be important. To some degree, it is likely that all three hypotheses interact. Future research should examine these questions in more detail, to address the important question of what effect spatial language has on spatial reasoning.

VII. CONCLUSIONS

In recent years interest has grown in the role of spatial language in early cognitive development (e.g., Bowerman & Choi, 2003; Ferrara et al., 2011; Pruden et al., 2011; Ratliff & Newcombe, 2008; Verdine et al., 2017). These studies look primarily at how a variety of spatial language word types influence thinking (e.g., size, location, shape terms). Dimension terms have long been an interest in the field of cognitive development, as their relational nature allows the examination of questions regarding the nature of language and thought (e.g., Bartlett, 1976; Gathercole, 1982; Ryalls, 2000). The studies described in this dissertation look at how to bridge these rich research areas, looking specifically at how dimensional adjectives, a subset of spatial language, relates to general language skill and spatial thinking.

Introducing the Measures

This dissertation introduces new measures to assess receptive dimensional adjective vocabulary in Spanish and in English for bilingual children, or for use with Spanish or English monolingual children. The new measures provide several features not available in prior assessments. As measures designed for a touchscreen tablet, not only can the measures collect children's correct or incorrect responses, but also their latency to respond. These measures also offers more engaging stimuli, by presenting children with images of toys, rather than cardboard cutouts of geometric shapes, as prior studies often relied on (e.g., Lindholm et al., 1979). Both the Spanish and English measures included 40 test trials, each with unique images of toys. The same bilingual speaker recorded audio for both measures. This measure offers an exciting new way to test children's knowledge of dimension terms.

Language Findings

The first study focuses on the new measures, and how Spanish and English language skills relate. Ninety-two bilingual preschoolers were tested on the two measures of dimensional adjective comprehension, and on receptive vocabulary in English and Spanish. We found that children's general vocabulary in one language predicts their dimensional vocabulary in that language, but there was no cross-language effect. These findings support convergent validity, showing that our measure is in line with an established measure of receptive vocabulary. Our study also observed that children are more likely to know only the unmarked term within a pair of dimensional adjectives than only the marked term. That is, a child would be more likely to know *large* and not *small*, than *small* and not *large*. One explanation is that the unmarked term can be used as a neutral term, while the marked term always gives information about relative size. For example, if one asks, "how *large* is your pool?" there is no information conveyed about the pool size, while the question "how *small* is your pool?" implies that your pool is likely smaller than average. The more general use of the unmarked, and likely increased frequency of use, allow children many opportunities to learn the unmarked terms. Overall, the primary contribution of study 1 is to establish the Spanish and English dimensional adjective comprehension tests as valid measures of knowledge of the tested terms.

The Spatial Scaling Study

The principle aim of the second study was to examine whether children's understanding of dimensional adjectives could predict their performance on the Spatial Scaling Test (SST). Looking at a sample of 92 Spanish-English bilingual children from

three through five years old, we tested children's general receptive vocabulary in both languages, children's dimensional adjective knowledge using the test described in chapters 3 and 4, and children's scores on the spatial scaling test. Rather than looking at Spanish and English dimensional comprehension as separate predictors of SST, a concept score was used, representing how many concepts, out of 8, children could identify in at least one language. This measure provides a holistic view of children's knowledge, and lacks the potential issues of collinearity posed by including separate scores for the languages. Multiple regression analysis confirmed that dimensional concept score predicts children's performance on the SST, even when controlling for children's age, and receptive vocabulary in English and Spanish.

In a separate analysis, including dimensional adjective comprehension separately for Spanish and English, only English scores emerge as a predictor. It is possible that children were primed to think in English while solving this task, given that the instructions for the game were given only in English and all tests given that day were in English. When examining which language children were stronger in, there were a few more children who showed English dominance over Spanish dominance, but overall English and Spanish dominance were fairly balanced for both general vocabulary and dimensional adjectives. Based on these findings, it is unlikely that the effect is due to children simply knowing more English than Spanish. Again, it is possible that part of the problem is that English and Spanish dimensional vocabulary are correlated, and a regression including both cannot accurately partition the variance. These limitations in mind, these findings have exciting implications for the development of children's understanding of space.

The current findings add to a growing body of research linking children's knowledge of spatial language to their performance on tasks involving spatial reasoning (e.g., Ferrara et al., 2011; Pruden et al., 2011; Verdine et al., 2017). By more thoroughly understanding how language relates to children's performance on complex cognitive tasks, we might better understand the complexities of early development. The current study adds to this body of research by showing similar results previously seen with more general spatial language use, specifically with dimensional adjectives. Additionally, this study was the first to look at the link between spatial language and spatial reasoning in bilingual children. Our results showed a stronger link between children's general and dimensional vocabulary in English and their performance on the SST. This may be attributable to the language of testing. If this is the case, it has important implications for the education of bilingual children, as it implies that the language instructions are given in may affect performance even on nonlinguistic tasks. Future research should directly examine this question, and whether teaching children dimension terms could improve their spatial scaling skill.

Children's Mental Transformations

The third and final study presented in this dissertation looked at predictors of children's performance on the Children's Mental Transformations Test (CMTT; Levine et al., 1999). While age was a consistent predictor of children's scores, neither dimensional adjectives nor general vocabulary predicted CMTT performance. We propose three possible accounts for this finding, considering the findings of Pruden et al. (2011), who found that children's early use of spatial language predicted later performance on the CMTT. The strongest explanation, given this finding and our findings

presented above regarding spatial scaling, is that the CMTT did not relate to dimensional adjective knowledge because the CMTT does not require the direct comparison of size. Rather knowledge of shape is likely a stronger predictor, terms also included in Pruden et al.'s (2011) analyses. Our second account is that receptive language might have less predictive power than expressive language. That is, that children who understand terms, but haven't started to use those words in expressive language yet, might be less able to draw on this knowledge in solving a task. Given that the children in our study were only tested on receptive language, they might not yet possess all these words in their expressive language, however, it is likely that many of the children have some dimensional adjectives in both expressive and receptive vocabularies. Finally, there is a possibility that it is early acquisition of spatial terms that predicts later spatial skill. This hypothesis is further supported by Verdine et al.'s (2017) finding that processing speed at three on shape terms predicted spatial skill at age five. A longitudinal study should be conducted to establish which of these proposals best fit children's patterns of learning.

Implications

The studies present above have exciting implications for both research and education. The measures developed for this dissertation offer a quick, easy, and fun way of assessing children's understanding of dimension terms. With an automated system there is less chance of experimenter error, limiting the likelihood of missing data. Additionally, the use of a touchscreen allows the collection of reaction time data, which previous measures did not easily allow. The game is fun for children, with the children who participated in our studies asking to play more games on the tablet. With a short testing time for the 40 trials, these measures could easily be implemented in any study of

spatial reasoning. The measures could also be adapted to be training tasks with the addition of feedback. For example, if a child selected the short toy, instead of the tall toy, there could be basic feedback, like, “That toy is short. Touch the tall toy”.

The findings of this research provide insight for early education of bilingual children. Although the results are not conclusive, study two suggests that the language children are tested in might affect performance. We did not see an effect of Spanish language skill on children’s performance on the SST, despite nearly 40% of children showing Spanish language dominance on dimensional terms. Although there are alternative explanations for this effect, it is definitely an area that requires future research. While the importance of testing bilingual children in both languages spoken has been firmly established for language measures (e.g., Hoff et al., 2012), these findings imply this might also be necessary to accurately gauge children’s ability in non-linguistic tasks.

Future Directions

There are many opportunities for future research building off this dissertation, but two potential studies are of the most importance. First, a longitudinal study would address many of the uncertainties presented in all three studies in this dissertation. By examining the development of dimensional adjectives over the first four or five years of children’s development, one could establish whether children who learn dimension terms earlier show a greater advantage on tasks of spatial reasoning. A longitudinal study would also could directly address the question raised in study one of whether children learn unmarked terms before marked terms.

The other important question for future research to address directly tackles the complexities of bilingualism. In the studies presented here, both general vocabulary and dimensional adjective knowledge were tested in both English and Spanish, but all the measures of spatial reasoning were given only in English. Since English on its own was a predictor of spatial scaling, but Spanish was not, we suspect that there may be a priming effect, where children draw on their knowledge of the language they are tested in more than their knowledge in their other language. By testing spatial skills in Spanish and English, we could directly address whether testing language impacts children's performance, as well as to what degree.

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APPENDICES

Table 1

Pooled Means and Raw Minimum and Maximum Values, and Standard Deviation

Variable	Mean	Minimum	Maximum	SD
PPVT	95.54	43	139	16.96
TVIP	85.92	55	122	19.22
Age	57.90	37.65	71.87	8.44
English Dimensions	3.71	0	8	2.57
Spanish Dimensions	3.32	0	10	2.83

Table 2

Regression Model with General Vocabulary predicting English Dimension Terms

	B	SE(B)	Sig.
Constant	-7.522	2.801	.007
PPVT	.040	.015	.009*
TVIP	.002	.012	.857
Age	.125	.012	<.001*

* $p < .05$

Table 3

*Regression Model with General Vocabulary predicting Spanish
Dimension Terms*

	B	SE(B)	Sig.
Constant	-6.904	3.192	.032
PPVT	.002	.016	.917
TVIP	.038	.015	.014*
Age	.117	.003	<.001*

* $p < .05$

Table 4

*Regression Model with Spanish Dimension Terms and General Vocabulary
predicting English Dimension Terms*

	B	SE(B)	Sig.
Constant	-6.191	3.003	.040
Spanish Dimension Terms	.189	.111	.089
PPVT	.039	.015	.010*
TVIP	-.005	.014	.721
Age	.103	.033	.002*

* $p < .05$

Table 5

*Regression Model with English Dimension Terms and General Vocabulary
predicting Spanish Dimension Terms*

	B	SE(B)	Sig.
Constant	-5.378	3.287	.104
English Dimension Terms	.205	.118	.083
PPVT	-.006	.017	.700
TVIP	.038	.015	.016*
Age	.091	.036	.011*

* $p < .05$

Table 6

Pairs of Unmarked and Marked Terms Tested

English		Spanish	
<u>Unmarked</u>	<u>Marked</u>	<u>Unmarked</u>	<u>Marked</u>
Large	Small	Grande	Pequeño
Big	Little	Enorme	Chiquito
Long	Short	Largo	Corto
Tall	Short	Alto	Corto
Fat	Skinny	Gordo	Flaco

Table 7

English and Spanish Words from Most to Least Comprehended

English		Spanish	
<u>Word</u>	<u>Pooled % Comprehended</u>	<u>Word</u>	<u>Pooled % Comprehended</u>
Tall	56.1%	Alto	51.7%
Small	53.0%	Grande	46.2%
Big	50.7%	Largo	44.1%
Large	48.9%	Chiquito	35.2%
Little	48.7%	Pequeño	30.0%
Long	47.5%	Enorme	28.2%
Short (length)	28.9%	Flaco	27.2%
Short (height)	28.9%	Corto (height)	24.0%
Fat	6.1%	Corto (length)	23.4%
Skinny	2.3%	Gordo	22.1%

Table 8

Summary of Missing Values for Chapter V

Variable	N	Percent Missing
SST #1	86	6.5
SST #2	87	5.4
SST #3	87	5.4
SST #4	86	6.5
SST #5	87	5.4
SST #6	86	6.5
SST #7	87	5.4
SST #8	87	5.4
SST #9	87	5.4
SST #10	86	6.5
SST #11	86	6.5
SST #12	87	5.4
SST #13	86	6.5
SST #14	86	6.5
SST #15	87	5.4
SST #16	86	6.5
SST #17	86	6.5
SST #18	85	7.6
SST #19	86	6.5
SST #20	86	6.5
SST #21	85	7.6
SST #22	87	5.4
SST #23	87	5.4
SST #24	86	6.5
PPVT	90	2.2
TVIP	63	31.5
English Dimension Score	91	1.1
Spanish Dimension Score	78	15.2

Table 9

<i>Pooled Means and Raw Minimum and Maximum Values</i>			
Variable	Mean	Minimum	Maximum
SST #1	46.37	0	161
SST #2	59.23	3	176
SST #3	52.55	0	224
SST #4	47.59	2	194
SST #5	33.17	0	124
SST #6	32.80	0	140
SST #7	33.87	0	176
SST #8	36.99	0	155
SST #9	40.67	6	154
SST #10	51.74	8	174
SST #11	48.24	6	155
SST #12	60.37	3	214
SST #13	43.89	7	174
SST #14	48.90	2	155
SST #15	41.97	2	214
SST #16	61.19	8	167
SST #17	32.04	1	140
SST #18	38.34	3	124
SST #19	38.88	0	155
SST #20	31.45	0	176
SST #21	52.72	0	166
SST #22	37.37	1	137
SST #23	57.69	3	223
SST #24	38.85	2	217
PPVT	95.54	43	139
TVIP	85.92	55	122
SST Mean	44.45	14.33	165.83

Table 10

Regression Model Predicting SST Score with Language

	B	SE(B)	Sig.
Constant	190.326	31.280	<.001
Spanish Dimensional Vocabulary	0.492	1.126	.662
English Dimensional Vocabulary	-2.769	1.135	.015*
PPVT	-.477	0.162	.003*
TVIP	-.049	0.155	.755
Age	-1.510	0.344	<.001*

* $p < .05$

Table 11

Regression Model Predicting SST Score with Reaction Time and Vocabulary

	B	SE(B)	Sig.
Constant	63.845	15.919	<.001
English Dimensional Vocabulary	-8.017	2.296	.001*
Spanish Dimensional Vocabulary	-1.038	1.815	.568
English RT Comprehended	.018	.009	.038*
Spanish RT Comprehended	.008	.006	.184
English RT Not Comprehended	-.023	.012	.055
Spanish RT Not Comprehended	-.005	.008	.506

* $p < .05$

Table 12

Regression Model Predicting SST Score with Concept Score and Controls

	B	SE(B)	Sig.
Constant	188.838	31.140	<.001
Concept Score	-2.714	1.378	.049*
PPVT	-.528	.158	.001*
TVIP	.030	.153	.845
Age	-2.462	.347	<.001*

* $p < .05$

Table 13

Pooled Means and Raw Minimum and Maximum Values for Chapter VI

Variable	Mean	Minimum	Maximum
CMTT	12.37	0	34
PPVT	95.06	43	139
TVIP	83.09	55	122
Age	60.48	47.97	71.87
English Dimensions	4.13	0	8
Spanish Dimensions	3.53	0	10

Table 14

Regression Model Predicting CMTT Score with Dimension Terms

	B	SE(B)	Sig.
Constant	-24.789	7.282	.001
Spanish Dimensional Vocabulary	.529	.312	.090
English Dimensional Vocabulary	.316	.291	.277
Age	.560	.125	<.001*

* $p < .05$

Table 15

Regression Model Predicting CMTT Score with Dimensional and General Vocabulary

	B	SE(B)	Sig.
Constant	-22.225	10.591	.036
Spanish Dimensional Vocabulary	.382	.333	.253
English Dimensional Vocabulary	.565	.321	.079
PPVT	.036	.046	.434
TVIP	-.062	.045	.171
Age	.541	.128	<.001*

* $p < .05$

FIGURES

Figure 1. Example of a test item. *"Touch the short toy" or "Toca el juguete corto"*

Figure 2. Children are asked to help the bear "Carla" find the toys she wants to play with.

Figure 3. Example of a practice item. *"Touch the cat" or "Toca el gato"*

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PUBLICATIONS AND PRESENTATIONS

Abad, C., Odean, R., & Pruden S. M., (2016, August) *Sex differences in spatial skill gains throughout pre-kindergarten*. Poster presented at Spatial Cognition 2016, Philadelphia, PA.

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