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Numerical Cognition in Bilingual Preschoolers

DISSERTATION

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for the degree of

DOCTOR OF PHILOSOPHY

in Psychology

by

Meghan C. Goldman

Dissertation Committee:
Associate Professor Barbara W. Sarnecka, Chair
Associate Professor Lisa Pearl
Professor Kourosh Saberi

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To Ryan and Sylas—the loves of my life.

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Portions of the research in this dissertation are currently published or in prep for publication. Specifically, research in Chapter 1 was published in *Developmental Science* (John Wiley & Sons Ltd) with co-authors James Negen and Barbara Sarnecka. Research in Chapter 2 is in prep for publication with co-authors Barbara Sarnecka and Ted Wright. Research in Chapter 3 is in prep for publication with co-authors Barbara Sarnecka and James Negen. This research was supported by NIH (R03HD054654) and NSF (DRL 0953521) grants to the dissertation chair, Barbara Sarnecka.

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CURRICULUM VITAE

EDUCATION

2014	Ph.D. in Psychology (Developmental Psychology) University of California, Irvine
2012	M.A. in Psychology (Developmental Psychology) University of California, Irvine
2009	M.A. in Psychology (Clinical Psychology) Pepperdine University, Graduate School of Education & Psychology
2007	B.A. in Psychology with Honors University of California, Santa Cruz

PUBLICATIONS

Goldman, M. C., Negen, J., & Sarnecka, B. W. (2014). Are bilingual children better at ignoring perceptually misleading information? A novel test. *Developmental Science.* doi: 10.1111/desc.12175

Sarnecka, B. W., Goldman, M. C., & Slusser, E. B. (2013). How counting leads to children's first representations of exact, large numbers. In R. Cohen Kadosh & A. Dowker (Eds.), *Oxford Handbook of Numerical Cognition*, NY: Oxford University Press.

CONFERENCE PRESENTATIONS

Goldman, M. C., Negen, J., Anaya, T. D., & Sarnecka, B. W. (2013, June). Numerical knowledge of low- versus higher-income bilingual preschoolers. Paper presented at the 43rd Annual Meeting of the Jean Piaget Society, Chicago, IL.

Goldman, M. C., Negen, J., & Sarnecka, B. W. (2013, May). Numerical knowledge of low-income bilingual preschoolers: A descriptive study. Poster presented at the 1st Annual Math Cognition Conference, Bethesda, MD.

Negen, J., Goldman, M. C., Anaya, T. D., & Sarnecka, B. W. (2013, April). ANS acuity and learning number words from number books and games. Poster presented at the Biennial Meeting of the Society for Research in Child Development, Seattle, WA.

Goldman, M. C., Negen, J., Anaya, T. D., & Sarnecka, B. W. (2013, April). Numerical knowledge of low- versus higher-income bilingual preschoolers. Poster presented at the Biennial Meeting of the Society for Research in Child Development, Seattle, WA.

Goldman, M. C. (2012, November). Knowledge of translation equivalents in the lexicons of bilingual preschoolers depends on word type. Poster presented at the 37th Annual Boston University Conference on Language Development, Boston, MA.

Goldman, M. C., Anaya, T. D., Negen, J., Flores, C., Alcala, C., Guzman, B., Jimenez, C., & Sarnecka, B. W. (2012, June). Bilingual preschoolers' early math skills in Spanish and English. Poster presented at the 11th Biennial Meeting of the National Head Start Research Conference, Washington, D.C.

Goldman, M. C., Anaya, T. D., Negen, J., Flores, C., Alcala, C., Guzman, B., Jimenez, C., & Sarnecka, B. W. (2012, June). A bilingual intervention to build preschool number concepts using counting books and a number line game. Poster presented at the 11th Biennial Meeting of the National Head Start Research Conference, Washington, D.C.

Goldman, M. C., Negen, J., & Sarnecka, B. W. (2011, October). Does the bilingual advantage in executive function extend to a number discrimination task? Poster presented at the 7th Biennial Meeting of the Cognitive Development Society, Philadelphia, PA.

Goldman, M. C., Negen, J., & Sarnecka, B. W. (2011, June). Does bilingualism help children ignore distracters on a number discrimination task? Poster presented at the 41st Annual Meeting of the Jean Piaget Society, Berkeley, CA.

Goldman, M. C. (2011, May). Number knowledge in bilingual preschoolers. Paper presented at Department of Cognitive Sciences Colloquium, University of California, Irvine.

Goldman, M. C. (2011, May). Cross-linguistic consistency within bilingual children: Are number words special? Paper presented at the 6th Annual Symposium on Cognitive and Language Development, Los Angeles, CA.

Sarnecka, B. W., Wright, C. E., & Goldman, M. C. (2011, March). Cross-linguistic associations in the vocabularies of bilingual children: Number words vs. color words and common nouns. Poster presented at the Biennial Meeting of the Society for Research in Child Development, Montreal, Quebec.

Goldman, M. C. (2010, May). Transforming sets: What changes are relevant to number words? Paper presented at the 5th Annual Symposium on Cognitive and Language Development, Irvine, CA.

HONORS & AWARDS

2014	Associate Dean's Fellowship, UCI School of Social Sciences
2013	Invited Participant, NIH Math Cognition Conference Poster Competition
2012	Associate Dean's Fellowship, UCI School of Social Sciences
2010	John I. Yellott Scholar Award, UCI Department of Cognitive Sciences
2010	UC Irvine Social Sciences Fellowship
2005-2009	Psi Chi, National Honor Society in Psychology
2007	Honors in Psychology, University of California, Santa Cruz
2007	College Eight Honors, University of California, Santa Cruz
2003-2005	Dean's List, California Polytechnic State University, San Luis Obispo
2003-2005	President's List, California Polytechnic State University, San Luis Obispo
2003-2005	National Society of Collegiate Scholars

ABSTRACT OF THE DISSERTATION

Numerical Cognition in Bilingual Preschoolers

By

Meghan C. Goldman

Doctor of Philosophy in Psychology

University of California, Irvine, 2014

Professor Barbara W. Sarnecka, Chair

The research on bilingualism and numerical cognition, especially in preschool-aged children, is markedly scarce. Therefore, in an effort to expand on the limited literature in this area, this dissertation is comprised of three separate studies looking at different aspects of numerical cognition in bilingual preschoolers. The first study investigates whether bilingual children are better than monolinguals at ignoring perceptually misleading information using a nonverbal numerical discrimination task. The second study compares the consistency of bilingual preschoolers' knowledge of number words across their two languages to their knowledge of color words and common nouns. The third study explores the numerical knowledge of low-income Spanish-English bilingual preschoolers, through examining whether their performance on a vocabulary measure and a battery of early math tasks depends on the language of testing, and by comparing their performance to that of higher-income bilinguals, low-income monolinguals, and higher-income monolinguals. Together, these studies provide insight into how learning more than one language may or may not impact various aspects of numerical cognition in children of this age.

INTRODUCTION

Over the past few decades, an increasing interest in the foundations of mathematical learning has resulted in a wealth of research on the nature and development of numerical cognition. *Numerical cognition* (also known as *number sense*) refers to the representation and processing of numerical content in the mind (Dehaene, 1997). It can be broken down into two categories: 1) nonverbal numerical cognition, and 2) symbolic numerical cognition (Jordan & Levine, 2009).

Nonverbal numerical cognition has been observed in infants, adults, and other animal species. It comprises of two distinct core systems that can represent numerical information: the *approximate number system* (ANS), which underlies the ability to represent the approximate cardinal values of sets of any size (i.e., up to several hundred), and the *parallel individuation system*, which underlies the ability to represent the precise number of individuals in small sets (i.e., up to three) (Feigenson, Dehaene, & Spelke, 2004). In contrast, s*ymbolic numerical cognition* involves the construction of positive integers, rational numbers, and real numbers. It is entirely dependent upon linguistic and cultural input, making it present in only a subset of humans (Feigenson et al., 2004; Gordon, 2004; Pica, 2004). Symbolic numerical cognition in preschoolers includes reciting the counting sequence, using counting to determine the number of objects in a set (i.e., understanding principles of one-to-one correspondence, stable-order, and cardinality), and understanding that numerical magnitudes increase linearly (Jordan & Levine, 2009).

In the area of symbolic numerical cognition, a robust pattern of number-concept development (i.e., learning the cardinal meanings of the number words) has been shown to take place between 2- to 4-years of age and takes many months (e.g. Carey, 2009; Fuson, 1988;

Wynn, 1992). During this period, children gradually work out how counting reveals the cardinal number of items in a set (Baroody & Price, 1983; Briars & Siegler, 1984; Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Fuson, 1988; Miller, Smith, Zhu, & Zhang, 1995; Slaughter, Itakura, Kutsuki, & Siegal, 2011; Wagner & Walters, 1982). In this process, they go through a series of *number-knower levels,* which are found not only for speakers of English, but also of Japanese (Barner, Libenson, Cheung, & Takasaki, 2009; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007), Mandarin Chinese (Le Corre, Li, & Jia, 2003; Li, Le Corre, Shui, Jia, & Carey, 2003), and Russian (Sarnecka et al., 2007).

This growing body of knowledge on numerical cognition in preschoolers has produced some important findings with regards to early foundations of math learning. For example, individual differences in the precision of the approximate number system have been demonstrated to be correlated to school math ability (Libertus, Feigenson, & Halberda, 2011). In addition, preschoolers' early math skills are the single best predictor of later mathematics achievement, as well as later academic achievement overall (Duncan et al., 2007). Furthermore, mathematics achievement is strongly related to a child's socioeconomic status (Jordan, Kaplan, Locuniak, & Ramineni, 2007). Therefore, the environment in which a child grows up seems to have an influence on aspects of numerical cognition.

Within the United States, demographics have been rapidly changing in recent years—this demographic shift has translated into increasing numbers of children with exposure to more than one language. The number of people who speak a language other than English at home make up 20% of the population in the U.S. and 43% in California (Shin & Kominski, 2010). Since numerical cognition plays an important role in early mathematics learning (Jordan & Levine, 2009), it is important to examine the influence that bilingualism may have on math development.

However, very few studies have explored this topic. Results from one such study (Bialystok & Codd, 1997) suggest that children's language status may affect their numerical abilities.

The research on bilingualism and numerical cognition, especially in preschool-aged children, is markedly scarce. Therefore, in an effort to expand on the limited literature in this area, this dissertation is comprised of three separate studies looking at different aspects of numerical cognition in bilingual preschoolers. Chapter 1 investigates whether bilingual children are better than monolinguals at ignoring perceptually misleading information using a nonverbal numerical discrimination task. Chapter 2 compares the consistency of bilingual preschoolers' knowledge of number words across their two languages to their knowledge of color words and common nouns. Chapter 3 explores the numerical knowledge of low-income Spanish-English bilingual preschoolers, through examining whether their performance on a vocabulary measure and a battery of early math tasks depends on the language of testing, and by comparing their performance to that of higher-income bilinguals, low-income monolinguals, and higher-income monolinguals. Together, these studies provide insight into how learning more than one language may or may not impact various aspects of numerical cognition in children of this age.

CHAPTER ONE: Are Bilingual Children Better at Ignoring Perceptually Misleading Information? A Novel Test

The impact of bilingualism on children's cognitive development has been an active yet controversial field of study for the better part of a century. The earliest scientific studies on this question tended to frame it in terms of general intelligence. In fact, many early studies in the first half of the twentieth century reported that bilingualism posed a threat to intellectual development (see Darcy, 1953; Diaz, 1983 for reviews). However, some later studies (e.g., Peal & Lambert, 1962) reported the opposite—better performance by bilingual children on measures of both verbal and nonverbal intelligence.

Today the question is framed not in terms of general intelligence, but in terms of more specific cognitive skills. For example, a recent meta-analysis investigating the cognitive correlates of bilingualism found that bilingualism is associated with increased attentional control, metalinguistic awareness, problem solving, symbolic and abstract representational abilities, and working memory (Adesope, Lavin, Thompson, & Ungerleider, 2010). There has been particular interest in the possibility that bilingualism may confer an advantage in suppressing misleading or irrelevant information, a key component of executive function (see Bialystok, 2001, 2009; Carlson & Meltzoff, 2008; Hilchey & Klein, 2011 for reviews). *Executive function (EF)*, also called *cognitive control* (Miller & Cohen, 2001), is a broad term for several interrelated higher-order cognitive processes, including inhibition, working memory, and cognitive flexibility. These processes assist in monitoring conflict and controlling attention (Diamond, 2006; Garon, Bryson, & Smith, 2008; Miyake et al., 2000).

Nonlinguistic interference tasks have often been used to investigate the effects of bilingualism on EF. For example, on the Simon task (Simon, 1969), participants must ignore the

position of a square presented on either side of a display, and attend only to its color, which corresponds to a left or right key press. Green squares, for instance, may correspond to a left key press and red squares to a right key press. On congruent trials, the square is presented on the same side as its associated key press (e.g., green squares on the left). However, on incongruent trials, the square is presented on the conflicting side (e.g., green squares on the right).

Performance on interference tasks such as this one has often been measured in two ways, by calculating: 1) an *interference effect,* or the difference in performance between congruent and incongruent trials, and 2) *overall performance,* or superior performance on both congruent and incongruent trials (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Hilchey & Klein, 2011). Evidence of a bilingual advantage has been asserted when either one or both of these effects have been found, meaning when bilinguals showed a smaller interference effect and/or better overall performance (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok & Martin, 2004; Bialystok, Martin, & Viswanathan, 2005; Costa, Hernández, & Sebastián-Gallés, 2008; Martin-Rhee & Bialystok, 2008).

There are at least two competing proposals for how bilingualism might enhance executive function. One prominent view originating from Green (1998) and promoted by Bialystok (2001) is that an advanced inhibitory control mechanism enables bilinguals to coordinate the joint activation of their two languages through the suppression of irrelevant information (i.e., the language not being used). Thus, bilinguals gain extensive practice selectively attending to relevant stimuli while ignoring irrelevant stimuli, resulting in a *specific* advantage in inhibitory control (Bialystok, 2001; Green, 1998). If bilinguals have a specific advantage in inhibitory control, then they should perform better than monolinguals only on incongruent trials because this is when misleading information is present. Better performance on incongruent trials would

result in a smaller interference effect on nonlinguistic interference tasks (Costa et al., 2009; Hilchey & Klein, 2011).

However, in a recent meta-analysis of studies that have looked for a bilingual advantage on interference tasks, Hilchey and Klein (2011) concluded that the smaller interference effect among bilinguals was scattered or nonexistent. Yet, there was a consistent and robust effect of better overall performance, casting doubt on the theory that a specific advantage in inhibitory control is responsible for bilinguals' better performance (Hilchey & Klein, 2011). An alternative view most formally put forth by Hilchey & Klein (2011) and supported by recent research (e.g., Costa et al., 2009; Kovács & Mehler, 2009) is that an advanced conflict-monitoring system allows bilinguals to adjust the level of executive functioning necessary to resolve a conflict between two competing, jointly activated representations (i.e., their two languages) to ensure an appropriate response. Therefore, bilinguals must selectively construct and access representations for each language, and continuously monitor and control the appropriate language during communicative interactions. This need to constantly manage two languages produces a domain-*general* executive functioning advantage that should be evident on a variety of cognitive tasks. If bilinguals have a general advantage in executive functioning, then they should perform better on both congruent and incongruent trials, resulting in better overall performance on these tasks (Hilchey & Klein, 2011).

Nonetheless, some studies have failed to find evidence for any bilingual advantage at all (either general or specific). For instance, Morton and Harper (2007) found that bilingual and monolingual children (matched on ethnicity and socioeconomic status) performed similarly on the Simon task. Likewise, Namazi and Thordardottir (2010) compared bilinguals and monolinguals on the Simon task, and found that children's working memory abilities, rather than

their language status, determined their superior performance on the task. Furthermore, Paap and Greenberg (2013) conducted three studies comparing bilingual and monolingual adults on several nonlinguistic interference tasks, including the Simon and color-shape switching tasks (studies 1-3), as well as the antisaccade (study 1) and flanker (study 3) tasks. Consistent with Hilchey and Klein's (2011) meta-analysis, Paap and Greenberg found no evidence of a smaller interference effect across any of their tasks. However, contrary to Hilchey and Klein, Paap and Greenberg also found no evidence of better overall performance in bilinguals than monolinguals (see Kousaie & Phillips, 2012; Humphrey & Valian, 2012 for related findings), and concluded that there is no clear evidence of bilingualism conferring other cognitive advantages.

One type of interference task that has not yet been used to explore bilingualism's effects is a numerical discrimination task. Bialystok and Codd (1997) did compare monolingual and bilingual preschoolers' understanding of cardinality (i.e., the idea that the last number used in a counting sequence tells the number of items in the whole set). In that study, children were shown pairs of block towers: one constructed from Lego blocks and the other constructed from Duplo blocks. These plastic blocks were identical except that the Lego blocks were half the size of the Duplo blocks. Children were asked to count the number of blocks in each tower to determine which tower had more. Bilinguals performed better on the task, which according to Bialystok and Codd, was because they were better at ignoring the size of the blocks and attending to their number.

The task used in the present study differs from the one used by Bialystok and Codd (1997) in that it is nonsymbolic (no number words or number symbols are used) and does not involve counting. In this task, children are shown a card with two arrays of dots. The child must decide which array has "more dots." This task is a standard one for assessing nonverbal

numerical ability (e.g., Halberda & Feigenson, 2008; Halberda, Mazzocco, & Feigenson, 2008; Wagner & Johnson, 2008; Xu & Spelke, 2000). In recent years, performance on this task has also been linked to performance on standardized math tests and school math achievement (Halberda, Mazzocco, & Feigenson, 2008; Halberda, Ly, Wilmer, Naiman, & Germine, 2012; Libertus, Feigenson, & Halberda, 2011).

Although this task is typically used to measure numerical estimation acuity, it has also been used in number/size congruency and Stroop-like interference paradigms (Cordes & Gelman, 2005; Gebuis, Kadosh, de Haan, & Henik, 2009; Hurewitz, Gelman, & Schnitzer, 2006). For example, Hurewitz et al. (2006) asked adults to judge which of two side-by-side dot arrays had more dots. All of the dots in any single array were the same size, but one array had larger dots than the other. On congruent trials, size was congruent with number (i.e., the array with larger dots contained more dots). The inverse occurred on incongruent trials (i.e., the array with smaller dots contained more). Participants were significantly better at determining which array had more dots on congruent than incongruent trials, suggesting that dot size interfered with numerical judgments. A similar finding was reported by Halberda and Feigenson (2008) with 3- to 5-year-old children.

These results suggest that people automatically extract a continuous quantity dimension (i.e., they can't help noticing the size of the individual dots), and that this dimension competes with number for attention. This makes the task a useful one for investigating possible effects of bilingualism on executive function in children.

In the present study, monolingual and bilingual children were presented with a standard, nonsymbolic, numerical discrimination task. We reasoned that any of three possible outcomes would be interesting. First, bilinguals might show a smaller interference effect than

monolinguals, supporting the idea that bilingualism confers a specific advantage in inhibitory control (e.g., Bialystok, 2001; Green, 1998). Alternatively, bilinguals might perform better than monolinguals overall, supporting the idea that bilingualism confers a general executive functioning advantage on this type of task (e.g., Costa et al., 2009; Hilchey & Klein, 2011). A third possibility was that we might find no differences in performance between bilinguals and monolinguals, either in terms of interference or overall (e.g., Morton & Harper, 2007; Paap & Greenberg, 2013). This result (which was in fact the result we found) provides no support for the idea of a bilingual advantage in executive function, either general or specific.

Method

Participants

Participants included 92 children with a mean age of 4 years, 9 months (*SD* = 10.2 months, range = 3;0 to 6;5). All participants were recruited from private or university-affiliated preschools in southern California where English was the language of instruction. At the time of recruitment, parents filled out a demographic form including a question about household income (see Duncan & Petersen, 2001). Income in all households exceeded $75,000 per year—the highest income category listed. Thus, no participants came from low-income households. Families received a prize (e.g., a small stuffed animal) when they signed up to participate in the study; no prizes were given at the time of testing.

Parental report was also used to estimate the percent of time the child was exposed to English and/or another language at home. How this information was collected depended on which of two larger studies the participant had originally been recruited for. Most participants (83%) were recruited as part of a larger study where parents were asked to list the family members and caregivers with whom the child interacted within a typical week (outside of

preschool and not counting the time when the child was asleep), to indicate the number of hours the child spent with each person, and the language(s) spoken with the child. If the same person used English and another language with the child, one-half of the time was allotted to English and one-half to the other language. Based on parents' responses, the number of hours of exposure to a language other than English was divided by the total number of hours of exposure to English and/or another language, and then converted to a percentage to estimate the percent of time the child was exposed to a language other than English at home. The remaining participants were recruited as part of a different study where parents were asked questions regarding what language they spoke most often with their child and what language their child spoke most often with them. Responses were based on a 5-point Likert scale where the options were "English only"; "Mostly English"; "Both languages about equally"; "Mostly another language"; and "Only another language." These responses were converted to a percentage that reflected the percent of time a language other than English was used at home ("English only" was converted to 0%; "Mostly English" to 25%; "Both languages about equally" to 50%; "Mostly another language" to 75%; and "Only another language" to 100%).

Of all participants, 32 children were only exposed to English at home (M = 4;7, SD = 9.7 months), 40 children were exposed to English and another language at home (M = 4;9, SD = 10.4 months), and 20 children were only exposed to a language other than English at home (M = 4;9, SD = 10.8 months). A total of 60 children were exposed to a language other than English: Chinese (n=24), Mandarin (n=8), Spanish (n=7), Hindi (n=3), Tamil (n=3), Cantonese (n=2), Farsi (n=2), Japanese (n=2), Korean (n=2), Czech (n=1), French (n=1), Gujarati (n=1), Hebrew (n=1), Italian (n=1), Tagalog (n=1), and Vietnamese (n=1).

Each child was tested once in English; testing occurred individually at the child's preschool. An additional 22 children were tested but not included in the data analysis: 12 (9 English only, 3 English & another language) were excluded because they did not complete the training trials, and 10 (6 English only, 4 English & another language) were excluded for not performing significantly above chance (56%) on any of the test trials. Children excluded from the analysis did not differ in any other ways from those who were included.

Materials[1]

For each trial of the numerical discrimination task, participants were shown two side-by-side arrays, containing between 20 and 100 black dots each, on a 21.5 × 12.5 cm laminated card. The arrays were generated in Matlab, printed on white paper, given a colored border (a different color was used for each ratio), and laminated. For the training trials, there were three blocks at an easy ratio of 1:3 (=.33). The 1:3 ratio was used as training because previous research has shown that even preverbal infants can discriminate numbers at that ratio (Feigenson et al., 2004). For the test trials, there were nine blocks with ratios at 1:2 (= .50), 7:12 (= .58), 2:3 (= .66), 17:24 (= .71), 3:4 (= .75), 4:5 (= .80), 5:6 (= .83), 7:8 (= .87), and 9:10 (= .90). There were eight trials per block, and all trials within each block contained the same ratio.

To generate the exact number of dots used for a given trial, first a lower number was chosen uniformly from 20 to 100 by Matlab. Then, it checked to see if there was an exact match that was also between 20 and 100, for a given ratio. For example, to generate a trial with a ratio of 2:3, first the number 50 was randomly chosen from 20 to 100 for one array, and then 75 was chosen as an exact match to make the other array (50:75 = 2:3). However, if the number 53 was randomly chosen first, then this would require the other array to have either 35.3 dots (35.3:53 = 2:3) or 79.5 dots (53:79.5 = 2:3), which is impossible. Therefore, the program would randomly

[1] Our thanks to Jessica Sullivan and David Barner for sharing a version of the task.

draw another number until an exact match was found. The sizes of the dots were generated in a similar way (generate a random size and see if there is an exact match, repeat as necessary). The dots within each array were all the same size. In each array, dots were clustered within a circle that was twice the summed area of all the dots. Therefore, the dots in the less numerous array did not seem more spread out, and the ratio of black to white space within the circle was always the same. The smaller array had to take up at least 20% of one side of the laminated card so that the dots could still be discriminated from each other.

There were two trial types (see Figure 1.1). On congruent trials, the numerically greater array was greater in total area (measured as the combined surface area of all of the dots in that array).[2] On incongruent trials, the numerically greater array was smaller in total area. The area ratio was the numeric ratio raised to an exponential power (1.5 for incongruent, 2.5 for congruent), in order to make it stand out clearly during the training trials. Half of the trials were congruent and half were incongruent. The side with the correct answer was counterbalanced, and the trial order was randomized within each block.

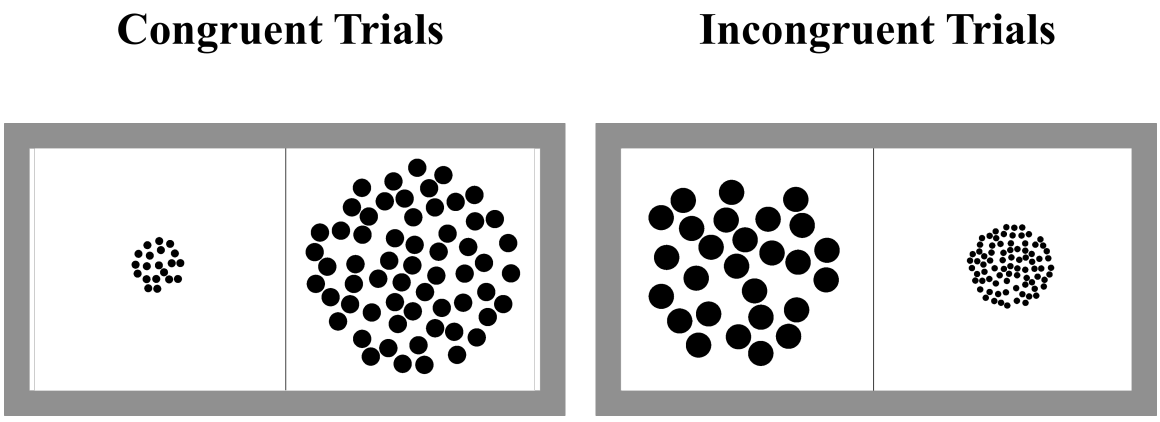

Figure 1.1. An example of the difference between congruent and incongruent trial types using training cards at the 1:3 ratio.

[2] Due to simple constraints of geometry, congruent trials were also congruent with respect to individual dot size, summed perimeter (the combined perimeter of all of the dots in an array), and incongruent with respect to density (the number of dots per unit area in the smallest possible circle around all of the dots in an array).

Procedure

The study began with training trials to ensure that participants understood the task (e.g., to make sure children did not think they were supposed to pick the side with bigger dots or greater total area). The experimenter said to participants, "Look at this card. This card has two sides. There are some dots on this side, and some dots on this side. (Experimenter points to each side.) You need to point to the side that has *more* dots. Which side has *more* dots?" If participants picked the wrong side on the training trials, the experimenter explained why it was wrong to help cue them into the task-relevant dimension of number rather than area. For example, if participants chose the side with bigger dots when there were more dots on the side with smaller dots, the experimenter said: "Well these dots are bigger, but *this* side has *more* dots. They're smaller, but there's *more* of them." To ensure that participants were not guessing, they had to answer eight training trials correct in a row before moving on to the test trials. (If necessary, trials were repeated in a cycle.) On the test trials, the experimenter asked, "Which side has more dots?" Feedback was given after every trial (e.g., "That's right—this side has more" or "Uh oh, this side has more dots, you see"); however, participants were no longer told why their response was incorrect. Trials were presented too rapidly for children to count the dots, and no children were observed attempting to count.

Data Analysis

Before conducting the main analysis, each child's overall performance and interference effect were calculated. Overall performance was computed by averaging proportion correct on both congruent and incongruent trials. The interference effect was calculated by taking the difference in proportion correct between congruent and incongruent trials. However, adjustments needed to be made to the calculation of the interference effect because participants were tested

on nine blocks of trials that each contained a progressively harder numeric ratio. Therefore, at some point, the blocks became so hard that children were no longer performing above chance (56%). This increase in difficulty would mask any interference effect, as chance performance might reflect difficulties discriminating at that ratio. Hence, an individual cutoff point was determined for each child by calculating the proportion correct on every block to establish at what ratio the trials became too difficult for that particular child. Then, only the blocks in which the child performed above chance were used to analyze the interference effect.

For the main analysis, age and percent of time a child was exposed to a language other than English at home were used as continuous variables. This allowed us to place children on a continuum of 0-100% exposure to a language other than English at home. On the extreme left of the continuum were children with sole exposure to English at home, in the middle were children with relatively equal exposure to English and another language at home, and on the extreme right were children with sole exposure to a language other than English at home.

However, since all of the children attended English-speaking preschools, it is not clear which children should be considered the "most bilingual." Thus, we approached the analysis using two different assumptions: (1) children with sole exposure to a language other than English at home are the most bilingual, and (2) children with relatively equal exposure to English and another language at home are the most bilingual. The logic behind these two assumptions is that children are more likely to spend time at their English-speaking preschools when they are older (e.g., five years old) than when they are younger (e.g., three years old). Therefore, according to the first assumption, at older ages, children with sole exposure to a language other than English at home and exposure to English at school might arguably be "more bilingual" than children with relatively equal exposure to English and another language at home and exposure to English at

school. To examine this assumption, a linear fit was used to determine whether children on the extreme right of the continuum would have better overall performance and/or a smaller interference effect than children on the rest of the continuum. In contrast, according to the second assumption, at earlier ages, children with relatively equal exposure to English and another language at home might be more bilingual than children with sole exposure to a language other than English at home. To examine this assumption, a quadratic fit was used to determine whether children in the middle of the continuum would have better overall performance and/or a smaller interference effect than children on the two extremes.

Finally, in order to make our results more comparable with extant literature (most of which treats bilingualism as a categorical variable), in a secondary analysis, participants were divided into the following three language groups: (1) children who were only exposed to English at home, (2) children who were exposed to English and another language at home between 40% and 60% of the time (i.e., relatively equal exposure to two languages), and (3) children who were only exposed to a non-English language at home. This excluded 25 children who did not fit into these categories. Children were then split into two groups based on median age: younger children (less than 4 years, 7 months) and older children. Using these categories, we analyzed the effects of age and language group, as well as an interaction between them.

Results

The average overall performance for all children was .695 (SD = .078), meaning that children correctly chose the side with more dots 69.5% of the time. Proportion correct was significantly higher on congruent (M = .794, SD = .131) than incongruent trials (M = .596, SD = .171), $t(182) = 8.827$, $p < .001$. Calculating an individual cutoff point removed a mean of 4.3 blocks (SD = 2.3 blocks). The average interference effect for all children was .090 (SD = .240).

Four simple linear regressions and two quadratic regressions were run for the main analysis (see Table 1.1). There was a significant linear effect of age on overall performance, $R^2(90) = .311$, $p < .001$, with older children performing better than younger children. In contrast, there was no significant linear effect of percent of time exposed to a language other than English at home on overall performance, $R^2(90) = .022$, $p = .155$, nor a significant quadratic effect, $R^2(90) = .039$, $p = .169$ (see Figure 1.2). Age was a significant linear predictor of the interference effect, $R^2(90) = .094$, $p = .003$. However, percent of time exposed to a language other than English at home was not a significant linear predictor of the interference effect, $R^2(90) = .002$, $p = .648$, nor a significant quadratic predictor, $R^2(90) = .007$, $p = .724$ (see Figure 1.3).

Table 1.1

Linear and Quadratic Regression Analyses

	Overall Performance			Interference Effect		
Predictor	Model 1 (Linear)	Model 2 (Linear)	Model 3 (Quadratic)	Model 4 (Linear)	Model 5 (Linear)	Model 6 (Quadratic)
Constant	.4539*** (.0384)	.6828*** (.0116)	.6753*** (.0130)	.4979*** (.1359)	.1020** (.0361)	.1144** (.0408)
Age	.0510*** (.0080)			-.0863** (.0283)		
Percent Exposure		.0003 (.0002)	.0012 (.0008)		-.0003 (.0006)	-.0018 (.0024)
Percent Exposure^2			.0000 (.0000)			.0000 (.0000)
R^2	.311	.022	.039	.094	.002	.007
F	40.613***	2.059	1.814	9.288**	.210	.324

Note. Unstandardized coefficients. Standard errors in parentheses.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

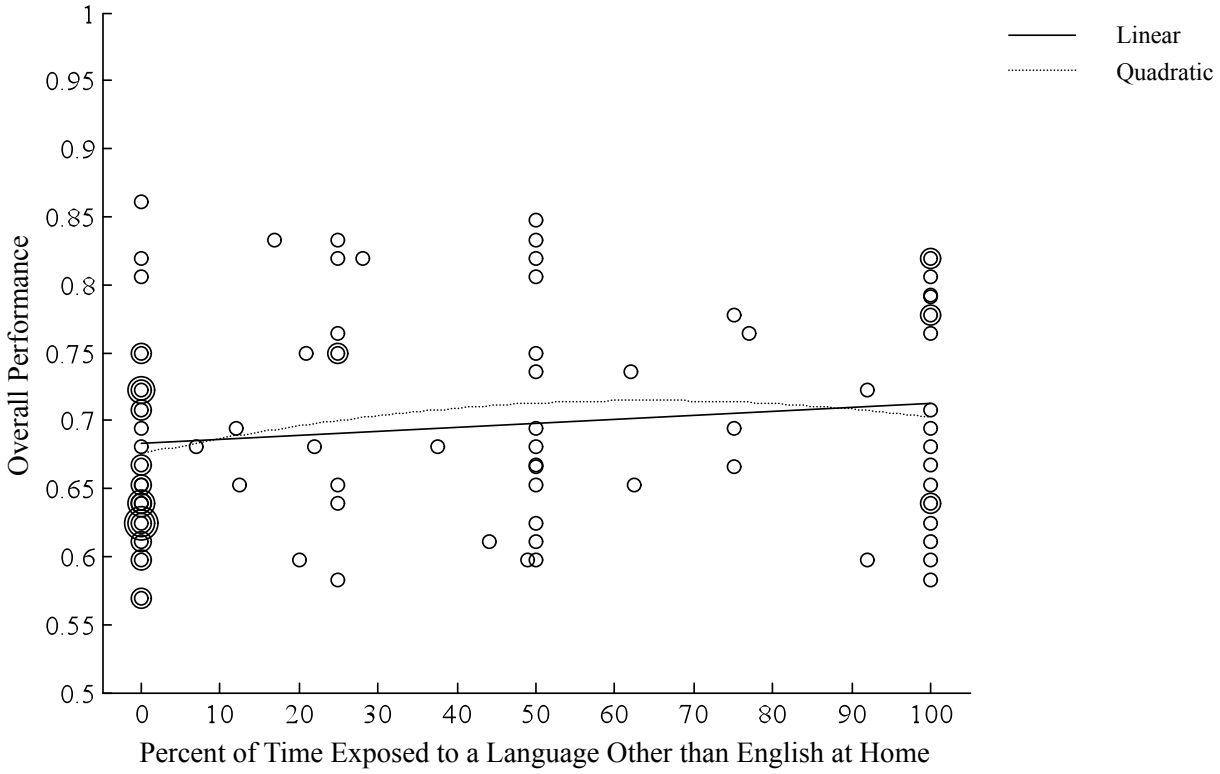

Figure 1.2. Percent of time exposed to a language other than English at home was not a significant predictor of overall performance (i.e., averaging proportion correct on both congruent and incongruent trials) using either a linear or quadratic fit. Note that additional concentric markers were used to denote when data overlap.

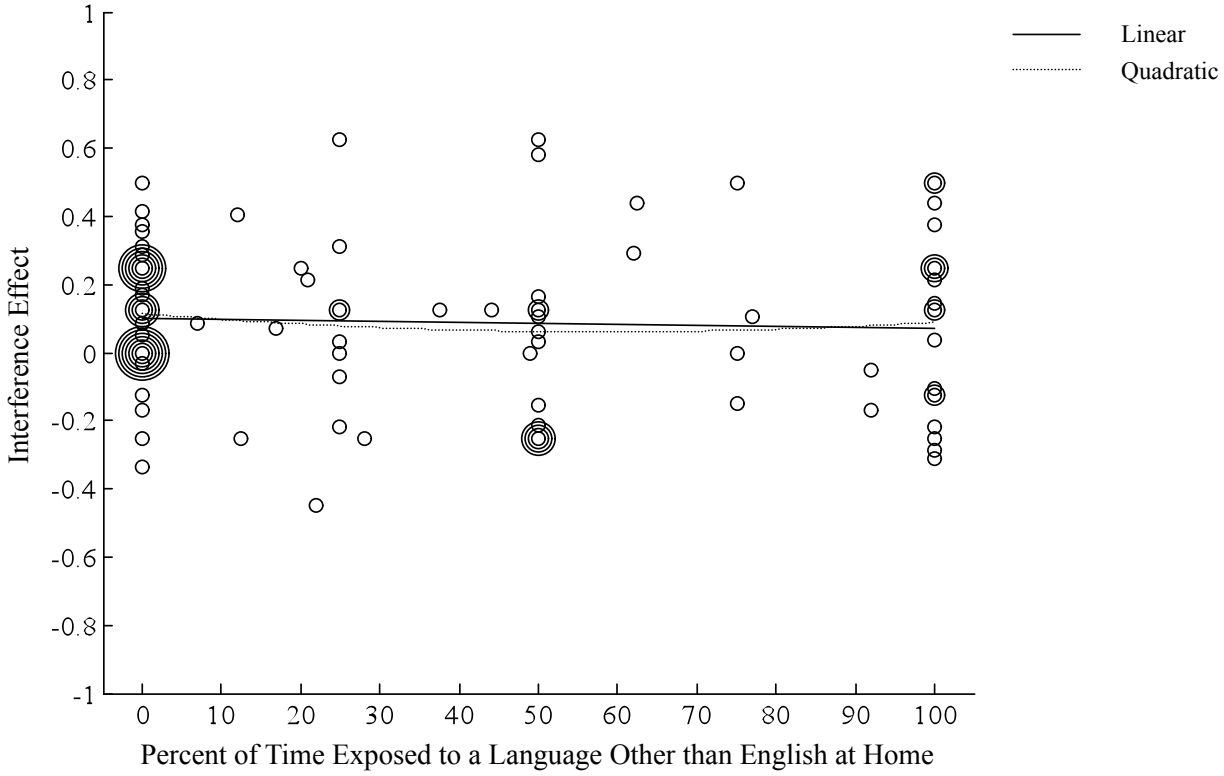

Figure 1.3. Percent of time exposed to a language other than English at home was not a significant linear or quadratic predictor of the interference effect (i.e., the difference in proportion correct between congruent and incongruent trials).

A 2 (Median Age; Younger than 4 years, 7 months vs. Older) × 3 (Language Group; English only exposure vs. Relatively equal exposure vs. Non-English only exposure) ANOVA was run for the secondary analysis. Table 1.2 shows the means and standard deviations for congruent trials, incongruent trials, overall performance, and the interference effect separated out by median age and language group. There was a main effect of age, with older children performing better, both in terms of overall performance, $F(1, 61) = 15.277$, $p < .001$, and the interference effect, $F(1, 61) = 5.687$, $p = .020$. However, there was no main effect of language group for either overall performance, $F(2, 61) = 1.814$, $p = .172$, or the interference effect, $F(2, 61) = .505$, $p = .606$. Furthermore, there was no interaction between age and language group for

overall performance, $F(2, 61) = 1.809$, $p = .172$, or the interference effect, $F(2, 61) = .995$, $p = .376$. Thus, the secondary analysis produced the same findings as the main analysis: older children performed better than younger children, but there was no effect of bilingualism on performance.

Table 1.2

Means (SDs) for Secondary Analysis

Congruent Trials				Overall Performance			
	English only exposure	Relatively equal exposure	Non-English only exposure		English only exposure	Relatively equal exposure	Non-English only exposure
Younger	.766 (.099)	.790 (.197)	.806 (.162)	Younger	.658 (.056)	.645 (.038)	.665 (.077)
Older	.804 (.136)	.793 (.095)	.796 (.102)	Older	.685 (.082)	.742 (.093)	.755 (.061)
Incongruent Trials				**Interference Effect**			
	English only exposure	Relatively equal exposure	Non-English only exposure		English only exposure	Relatively equal exposure	Non-English only exposure
Younger	.550 (.109)	.500 (.252)	.525 (.154)	Younger	.137 (.218)	.152 (.352)	.179 (.256)
Older	.566 (.128)	.691 (.143)	.713 (.185)	Older	.102 (.168)	-.054 (.163)	-.001 (.259)

Discussion

The goal of the present study was to use a novel task (the nonsymbolic numerical discrimination task) to look for differences between bilinguals and monolinguals, either in terms of an interference effect or overall performance. We found no such differences.

There are several reasons to be confident that the task was developmentally appropriate and measured what it was supposed to measure. First, the numerical discrimination performance of children in this study was consistent with findings from other studies using the same task with children of this same age (e.g., Halberda & Feigenson, 2008). Second, the analysis of interference effects excluded blocks where the child's performance dropped to chance levels. In other words, we only looked for interference at the ratios we knew the child could discriminate. Third, all children performed better on congruent than incongruent trials, confirming that area functioned as a distractor dimension. And fourth, older children performed better than younger children (i.e., had both a smaller interference effect and better overall performance), confirming that the task was developmentally sensitive.

Thus, our results differ from studies that have reported a bilingual advantage specifically in inhibitory control (e.g., Bialystok, 2001; Green, 1998), or better performance by bilinguals on another measure of numerical cognitive development (Bialystok & Codd, 1997). Our results also fail to support the idea that bilinguals outperform monolinguals generally on such tasks (e.g., Costa et al., 2009; Hilchey & Klein, 2011), as we found no effects of bilingualism on overall performance.

In short, our findings are most consistent with those previous studies that have argued against a bilingual advantage (either general or specific) in executive function (e.g., Humphrey & Valian, 2012; Kousaie & Phillips, 2012; Morton & Harper, 2007; Namazi & Thordardottir, 2010;

Paap & Greenberg, 2013). The present study used exactly the sort of task on which bilinguals should outperform monolinguals, and had sufficient power to detect age-related differences in both the interference effect and overall performance. This suggests that any advantage conferred by bilingualism must be much smaller than the improvement that happens normally with development across this age range.

Of course it is possible that a bilingual advantage exists, but did not show up in this study. For example, our measure of performance (accuracy) might not have been sensitive enough to detect a bilingual advantage on this task. Previous research reporting a bilingual advantage typically used response times in addition to accuracy, because of ceiling effects on accuracy (Hilchey & Klein, 2011). Although response time data would be nice to have, it is notoriously difficult to collect meaningful reaction times from children this young. However, since our participants responded correctly only 69.5% of the time, we are confident that ceiling effects were not a problem in the present study.

A related possibility is that the processing demands of our task were not high enough to elicit a bilingual advantage. Martin-Rhee and Bialystok (2008) found a bilingual advantage on the Simon task only when children were required to respond immediately after the display was presented. However, monolinguals and bilinguals performed equivalently when a delay occurred before responding, making the task easier. Although our task was presented rapidly and children did respond quickly, it is possible that a bilingual advantage would have appeared if task demands were even higher. (Note, however, that task demands were high enough to produce interference effects—better performance on congruent than incongruent trials—for all children.)

In sum, we find no evidence for a bilingual advantage, either general or specific, on this task, in children of this age. This finding alone does not negate the many reports of a bilingual

advantage on other tasks, but it does contribute to a growing body of evidence that calls the bilingual advantage into question. We hope that these findings will contribute to a more detailed understanding of how speaking one versus more than one language may affect—and also how it may not affect—other aspects of a child's cognitive development.

CHAPTER TWO: Cross-Linguistic Associations in the Lexicons of Bilingual Preschoolers: Number Words vs. Color Words and Common Nouns

Word learning is a famously complicated problem. Consider Quine's (1960) well-known "gavagai" scenario in which a linguist goes to a foreign place to learn the native language. Upon arriving, the linguist hears an inhabitant say "gavagai" while pointing to a rabbit running in the field. How does the linguist determine what the inhabitant is referring to when he says "gavagai"? Does the word refer to the rabbit? To its brown, floppy ears or white, bushy tail? To the act of running? To the field? According to Quine, because learners are presented with an infinite number of possible referents in the world, learning a new word is a seemingly impossible task.

And yet, children do it all the time. In fact, a child acquiring language has a lot of words to learn; a child learning two languages has even more. An interesting and recurring question in the research literature is whether young bilinguals possess an identical word in each of their languages for a single referent (often called *translation equivalents*). Specifically, do they know a word for a specific object, like a plane in, for example, Spanish "avión," and know the word for this identical object in their other language, for example, English "plane." Previous research has shown that translation equivalents are common in bilingual children's lexicons; they make up about 30% of all of the words that they know, in both of their languages (Holowka, Brosseau-Lapré, & Petitto, 2002; Pearson, Fernandez, & Oller, 1995; Sheng, Lu, & Kan, 2011). However, it is not known whether bilinguals' knowledge of translation equivalents is dependent on word type.

One domain of word learning that has been of particular interest to cognitive developmental researchers is the domain of number words. A robust pattern of number-word

learning has been shown to take place between 2- to 4-years of age and takes many months (e.g., Carey, 2009; Fuson, 1988; Wynn, 1992).[3] Children first learn to recite the count list at around two years old. At this point, they learn the counting sequence as a meaningless ordered list, much like how children learn other arbitrary sequences, such as "eeny, meeny, miny, mo." They first think of the count list as an unbroken chain, so they can only say the number words by producing the whole sequence. They do not realize that the sequence contains separate words (Fuson, 1988), similar to how children first learning the alphabet do not realize that "LMNOP" contains five different letters. As they gain more experience with counting, children learn that the number words are separable, and can often engage in the routine of counting (i.e., touching one object in a set at a time as they recite the counting sequence) (Fuson, 1988). However, it takes children one-and-a-half to two years to work out how counting reveals the cardinal number of items in a set (Baroody & Price, 1983; Briars & Siegler, 1984; Frye et al., 1989; Fuson, 1988; Miller et al., 1995; Slaughter et al., 2011; Wagner & Walters, 1982).

During this extended learning period, children go through *number-knower levels* (Carey, 2004; Carey, 2009; Condry & Spelke, 2008; Le Corre, Van de Walle, Brannon, & Carey, 2006; Sarnecka & Carey, 2008; Sarnecka & Lee, 2009; Wynn, 1990, 1992). First, children learn what "one" means and believe that all other number words in their count list mean "more than one." For instance, if you ask children in this stage to give you four, six, or nine grapes, they will always give you more than one grape but will also always just grab a bunch. They will not necessarily give a larger number when asked for nine grapes than when asked for four grapes. However, if you ask them to give you one grape at several different times, they will reliably give you only one grape every time. Children at this stage are called *one-knowers* because they only

[3] The ages at which children learn to count and acquire number concepts come from studies that primarily used participants from higher-income families. Research by Fluck and Henderson (1996) suggests that low- and middle-income children learn the cardinal principle six months later than higher-income children.

know the meaning of the word "one" among all the words in their count list. They stay in this stage for about six to nine months before learning what the word "two" means. Children who know the meaning of "two" will give two items when asked for "two" and one item when asked for "one," but will just give a handful (that is always more than two) when asked for any other number in their count list. These children are known as *two-knowers.* Children remain at this stage for another several months until they become *three-knowers* and then sometimes *four-knowers*. Sometime after the three- or four-knower level, children seem to make an inductive generalization about the relations between words in the list and their successive cardinalities. That is, they seem to recognize that the same relation (which might be expressed as, 'next word means plus one') exists between "one" and "two," between "two" and "three," and between "three" and "four." When children implicitly generalize this rule to higher number words ("five, six...") it gives them a way to understand what all the cardinal number words mean. Children who have made this induction are called *cardinal principle knowers* (or *CP-knowers)*.

Number-knower levels have been found not only for speakers of English, but also for speakers of other languages, including speakers of Japanese (Barner et al., 2009; Sarnecka et al., 2007), Mandarin Chinese (Le Corre et al., 2003; Li et al., 2003), and Russian (Sarnecka et al., 2007). In fact, in every culture that has been studied, children go through these stages of working out how to use counting to determine the cardinality of a set (Carey, 2004).

One current proposal about this protracted pattern of development is that number-word learning occurs through a conceptual-role bootstrapping process (Carey, 2009; see also Block, 1986; Quine, 1960). In this process, children first learn a placeholder structure (i.e., the ordered list of number words as part of the counting routine) and then gradually fill this structure in with meaning (i.e., learn the cardinal meanings of the number words and their ordinal relations to one

another). In other words, at the beginning, children learn to recite the count list without knowing what each word means. Then, over a period of one to two years, children progressively imbue the words with meaning, piece-by-piece. In doing so, they are actually constructing the concepts that the words will stand for. Under Carey's (2009) conceptual-role bootstrapping account, the process of learning what the number words mean *is* the process of acquiring natural-number concepts.

Number-word learning is therefore distinct from other types of word learning. Different types of words may present different challenges (Bloom, 2000), especially when learning two languages. For common nouns like "rabbit" and adjectives like "red," there is something in the environment, an individual or property of an object that these words pick out. You can point out a rabbit or something that is red. However, in learning two languages, knowing the word "rabbit" in one language and being able to point out a rabbit (indicating that you have learned the meaning of that word) does not help you figure out what the word for rabbit is in your other language. This is exemplified by Quine's "gavagai" scenario. In contrast, for number words, like "three," they have no physical manifestation in the environment. You cannot point at a single entity and call it "three" (unless you are holding up a card with the numeral three on it!). Number words do not refer to a particular object or property of objects; they refer to properties of sets. This makes number-word learning difficult initially. Yet, in learning two languages, if you have constructed a concept of "three" in one of your languages, it should be relatively easy to translate it into your other language because the count list of each language provides a structure such that when you know the cardinal meaning of the third number in one count list you can generalize it to the third word in your other count list. This structure is what makes number words so simple to translate; once you have a concept of the cardinal meaning of a particular number, you know

the cardinal meaning of the word in the corresponding position in the count list of every possible language. So, if you have a concept for 27 in one language, then you know the cardinal meaning of the twenty-seventh word in the count list of any other language (you just have to learn the language!).

Thus, Carey's view of number-word learning gives rise to two predictions about the number-concept development of bilingual learners. (1) Learning number words in a first language is significantly different from learning number words in a second language; there is great difficulty in learning the cardinal meanings of the number words in one's first language, but these meanings are easily translated. (2) As a result of the structure provided by the count list, it should be easier to translate number words across languages than other types of words. Since children learn the phonological forms of the number words (i.e., the count list) well before they learn their cardinal meanings, children learning the cardinal meaning of a number word are not constrained by a lack of knowledge of the label for the number. However, they are greatly constrained by the cardinal meanings they already know. For example, if a bilingual child knows the concepts of "one," "two," and "three," then she could at most know the cardinal meanings of the first three number words in each language. On the other hand, it would not be expected for her to know the cardinal meanings of the first six number words in English before knowing the cardinal meanings of any number words in Spanish. Therefore, Carey's (2009) conceptual-role bootstrapping account gives rise to an empirical prediction: Number-word knowledge should be *more consistent* across the two languages of a bilingual learner than knowledge of other word types.

The present study tested this prediction with Mandarin-English and Spanish-English bilingual preschoolers, by comparing the consistency of their knowledge of number words across

their two languages to that of color words and common nouns (words for animals and vehicles). If our understanding of number-word learning and number-concept construction is correct, then children's number-word knowledge should be much more correlated across their two languages than their knowledge of words in other domains.

Method

Participants

Participants included 20 Mandarin-English bilinguals with a mean age of 4 years, 2 months (*SD* = 6.5 months, range = 2;11 to 5;2) and 30 Spanish-English bilinguals with a mean age of 4 years, 3 months (*SD* = 6.4 months, range = 3;0 to 5;6).

Mandarin-English bilinguals were recruited from private or university-affiliated preschools, which predominately serve children from higher-income households. Spanish-English bilinguals were recruited from Head Start programs or private preschools, which predominately serve children from low-income households. English was the language of instruction at all of the preschools, which were all located in southern California. At the time of recruitment, parents filled out a demographic form asking them about their child's language status (i.e., the percent of time the child was exposed to English and/or another language at home). Mandarin-English bilinguals were exposed to Mandarin at home 72% of the time, and Spanish-English bilinguals were exposed to Spanish at home 62% of the time, on average.

Families received a prize (e.g., a small stuffed animal) when they signed up to participate in the study; no prizes were given at the time of testing. Testing occurred individually at the child's preschool. An additional 26 children were tested but not included in the data analysis: 21 Mandarin-English and 5 Spanish-English bilinguals were excluded because they responded

correctly to all trials of one or more word types in both languages, indicating that they were too advanced for the study.

Materials and Procedure

Each child was tested twice on the Give-X and Counting Objects tasks in two 20-minute sessions that occurred on different days within a two-week period. Participants were tested on both tasks in English in one session and in the child's other language in the other session. Order of sessions (i.e., the language tested first) was counterbalanced across participants. Task protocols were translated into Mandarin and Spanish by native speakers of those languages who were also fluent speakers of English. A fluent, native speaker of the test language always conducted the testing.

Give-X Task. The purpose of this task was to assess children's knowledge of number words, color words, and common nouns in each of their languages. It is an expanded version of the Give-N task (Wynn, 1990, 1992), which is often used to assess children's number-word knowledge.

To set up the task, the experimenter put nine stuffed animals and nine plastic containers, each consisting of a set of 12 small, plastic toys (approx. 3 cm in diameter), on the floor next to the testing table. Each stuffed animal was placed on top of one of the containers. The authors decided in the design phase of the study which stuffed animal would be paired with which container. A large t-shirt was placed over all of the stuffed animals and containers to hide them from view. The set up was done before the child arrived.

There were nine blocks (one for each stuffed animal/container pair) of six trials each, presented in a randomized order, as determined by the child. Trials within each block were presented in a preset, randomized order. To begin the task, the experimenter uncovered the

stuffed animals and said, "I brought all my friends to play with. Who do you want to play with first?" (For each subsequent block, the experimenter said, "Now who do you want to play with?") Once the child picked one of the stuffed animals, the experimenter picked up the container of toys that was paired with the chosen animal, and covered up the rest of the animals and containers again. (Allowing the child to choose the stuffed animal for each block served to randomize block order, as well as to keep participants engaged in the task.)

The experimenter placed the stuffed animal (e.g., a kitty) and the container on the table, and said, "Kitty likes to play with these. (Experimenter takes the lid off of the container and shows contents to the child.) And, this is kitty's plate. (Experimenter holds up the lid.) In this game, you're going to give something to the kitty. I'll tell you what to give him, and you put it on his plate and slide it over to him, like this. (Experimenter pretends to put an object on the lid, and then slides the lid over to the stuffed animal.) Ready? Can you give the kitty a *car*? Once the child slid the lid with the car on it over to the kitty, the experimenter asked, "Is that a *car*?"

Of the nine blocks, three tested the child's knowledge of number words, three tested color words, and three tested common nouns (words for animals and vehicles). In the three 'number' blocks, the child was given a container of 12 identical objects (fish, rocks, or bells) and, on each trial, was asked to give some number (1 to 6) of them to a stuffed animal (e.g., "Can you give the penguin *three* bells? Is that *three*?"). In the three 'color' blocks, the child was given a container of 12 objects of the same shape (frogs, dinosaurs, or cubes) but different colors, with 2 each of red, orange, yellow, green, blue, and purple. On each trial, the child was asked for an object of a certain color (e.g., "Can you give the alligator a *green* frog? Is that *green*?"). In the three 'common noun' blocks, the child was given a container of 12 objects (wild animals, farm animals, or vehicles) that differed in both type and color (e.g., 2 black gorillas, 2 grey elephants,

and 2 orange tigers). On each trial, the child was asked for a type of object (e.g., "Can you give the dinosaur a *gorilla*? Is that a *gorilla*?").

Counting Objects. Children were asked to count ten evenly spaced buttons, on a 65.5 × 10 cm corkboard, to assess their knowledge of the count list in both of their languages. The experimenter asked children to count the buttons (e.g., "Can you show me how you count these?"). When children were reluctant to count, they were encouraged to do so by the experimenter. For example, when children did not start counting on their own, the experimenter pointed to the leftmost button, said the number word for "one," and then pointed to the next button. If children stopped counting before they reached the number word for "ten," the experimenter would repeat the last two number words they said with a rising intonation (e.g., "three, four…?"). Or, the experimenter would ask, "What comes after N?" (where N was the last number word produced by the child). If the child still did not continue counting, his or her counting sequence was considered to end at the last number word he or she produced. Children were asked to count twice. Counting was coded as correct up to the point of the first error, and children's highest correct count was used in the analysis.

Data Analysis

For the Give-X task, the raw data are dichotomous—the correct item(s) were selected by the child or not—and a child's performance on a specific word type (number words, color words, or common nouns) can be summarized by collapsing across the three blocks for that word type to produce a 2 x 2 contingency table containing up to 18 observations. In this table, one dimension codes correct/incorrect for trials in English, and the second dimension codes correct/incorrect for trials in either Mandarin or Spanish. Therefore, for each word type, the table shows the number of times that the child got a specific word correct in both languages, only correct in English, only

correct in the other language, and/or incorrect in both languages (see Figure 2.1). Although a reasonable summary of the data for a specific word type can be produced by also collapsing these 2 x 2 tables across children, the chi-square test of association, often performed for such tables, would not be appropriate for the resulting table. This test assumes independence of the observations; however, the inclusion of the, up to 18, presumably correlated, observations from each child in the contingency table, violates that assumption.

	Other Language		
English		**Incorrect**	**Correct**
	Correct		Blue (2) Green (2) Red (3) Purple (2) Orange (3) Yellow (2)
	Incorrect	Yellow (1)	Blue (1) Green (1) Purple (1)

Figure 2.1. An example of a 2 x 2 contingency table for an individual child's performance on the three 'color word' blocks, containing 18 observations (the numbers in parentheses indicate the number of times an observation occurred).

The approach used here to circumvent this problem is to compute a phi (ϕ) value, a standard measure of association used for dichotomous data, for each child's three 2 x 2 contingency tables (one per word type). Then, the resulting phi values can be analyzed using standard repeated-measures analysis of variance methods. Similar to a Pearson's *r*, phi is a correlation coefficient that can have values between -1 and +1. A value of zero would indicate

that there is no correlation between the words a child got correct in English and the words she got correct in another language (e.g., a child got "one," "two," and "three" correct in English but "four," "five," and "six" correct in Mandarin). A value of 1 would indicate that a child got the same words correct or incorrect in both languages. A value of less than zero would not be expected for these data, because it would reflect a situation in which a child's increasing probability of being correct on certain words in English would be associated with a lower probability of being correct on those same words in the other language. However, such an outcome can occur and did for isolated instances in these data. If c_{ij} indicates the counts in row i and column j of a 2 x 2 table, then phi is computed according to the formula:

$$\phi = \frac{c_{11}c_{22} - c_{12}c_{21}}{\sqrt{(c_{11} + c_{12})(c_{21} + c_{22})(c_{11} + c_{21})(c_{12} + c_{22})}}$$

One issue for this use of phi is that a non-trivial number of participants were correct on all trials of a particular word type in one or the other of the two languages. Looking at the equation for phi, it becomes clear that this outcome creates a problem. The denominator in this formula is a product of the four row and column sums. If any of these sums is zero, their product is zero, and dividing by zero creates an undefined result. To avoid this problem, we adjusted the count in each cell of the 2 x 2 contingency table. The adjustment used is based on the premise that these counts are random samples and involves a slight regression toward the mean. The size of this additive adjustment was 1% of the difference between the raw count and the mean of the table (i.e., the total count in the table divided by four). The following equation is an example of the adjustment for one cell:

$$Adjusted\ c_{11} = \left[\left(\frac{c_{11} + c_{12} + c_{21} + c_{22}}{4} - c_{11}\right)(0.01)\right] + c_{11}$$

To get a sense for the effects of this adjustment, consider the following 2 x 2 table: [4 7; 5 2]. Here the 4 and 7 are the top row. They indicate that the child responded correctly in English but incorrectly in the other language four times, and responded correctly in both languages seven times. The 5 and 2 in the bottom row indicate that the child responded incorrectly in both languages five times, and responded incorrectly in English but correctly in the other language two times. The unadjusted phi for this table is .342; the adjusted phi for this table is .338. Generally, when all of the cells in a 2 x 2 table are non-zero, this adjustment has a negligible effect.

Of course, the point of the adjustment is to obtain usable data in cases where one row or column of a table is zero. Consider two cases in which a child responded correctly to all trials in English. In the first such table, the counts are [9 9; 0 0], meaning that the child responded correctly in English but incorrectly in the other language nine times, and responded correctly in both languages nine times—resulting in correct responses for all trials in English. Because of the zeroes in the bottom row, the unadjusted phi would be undefined in this case; however, the adjusted phi is 0.0, which seems reasonable because there really is no association here. In the second such table, the counts are [2 16; 0 0], meaning that the child responded correctly in English but incorrectly in the other language two times, and responded correctly in both languages sixteen times – again resulting in correct responses for all trials in English. Instead of being an undefined result, the adjusted phi for this table is .086, suggesting that there is weak evidence of an association. By contrast, if the 2 counts in the last example, for which the child responded correctly in English but incorrectly in the other language, had been incorrect in both

languages instead (i.e., if the table had been [0 16; 2 0]). Then, the unadjusted phi would be 1, but the adjusted phi used in the analysis would be .975.

Results

Give-X Task

Phi, with possible values between -1 and +1, was used to measure the correlation between a child's ability to respond to a request in English and her ability to respond to the same request in her other language. For Mandarin-English bilinguals, the mean phi for number words was .267 (*SD* = .289), the mean phi for color words was .130 (*SD* = .239), and the mean phi for common nouns was .146 (*SD* = .340). For Spanish-English bilinguals, the mean phi for number words was .569 (*SD* = .344), the mean phi for color words was .024 (*SD* = .217), and the mean phi for common nouns was .111 (*SD* = .276).

A two-way mixed ANOVA was conducted with word type (number words vs. color words vs. common nouns) as the within-subjects factor and language group (Mandarin-English vs. Spanish-English bilinguals) as the between-subjects factor. There was a main effect for word type, $F(2, 96) = 18.568$, $p < .001$, but not for language group, $F(1, 48) = 1.420$, $p = .239$. However, these effects were qualified by a significant interaction between word type and language group, $F(2, 96) = 6.507$, $p = .002$ (see Figure 2.2). A simple main effects analysis for language group revealed that there was a statistically significant difference in phi values between Mandarin-English and Spanish-English bilinguals for number words, $F(1, 48) = 10.431$, $p = .002$, but not color words, $F(1, 48) = 2.629$, $p = .111$, or common nouns, $F(1, 48) = 0.162$, $p = .689$. A simple main effects analysis for word type demonstrated that phi values did not significantly differ based on word type for Mandarin-English bilinguals, $F(2, 38) = 1.144$, $p = .329$; however, they did for Spanish-English bilinguals, $F(2, 58) = 32.087$, $p < .001$. Pairwise

comparisons showed that, for Spanish-English bilinguals, number words had a higher phi on average than color words, (M = .545, SE = .076, p < .001), and common nouns, (M = -.458, SE = .083, p < .001).

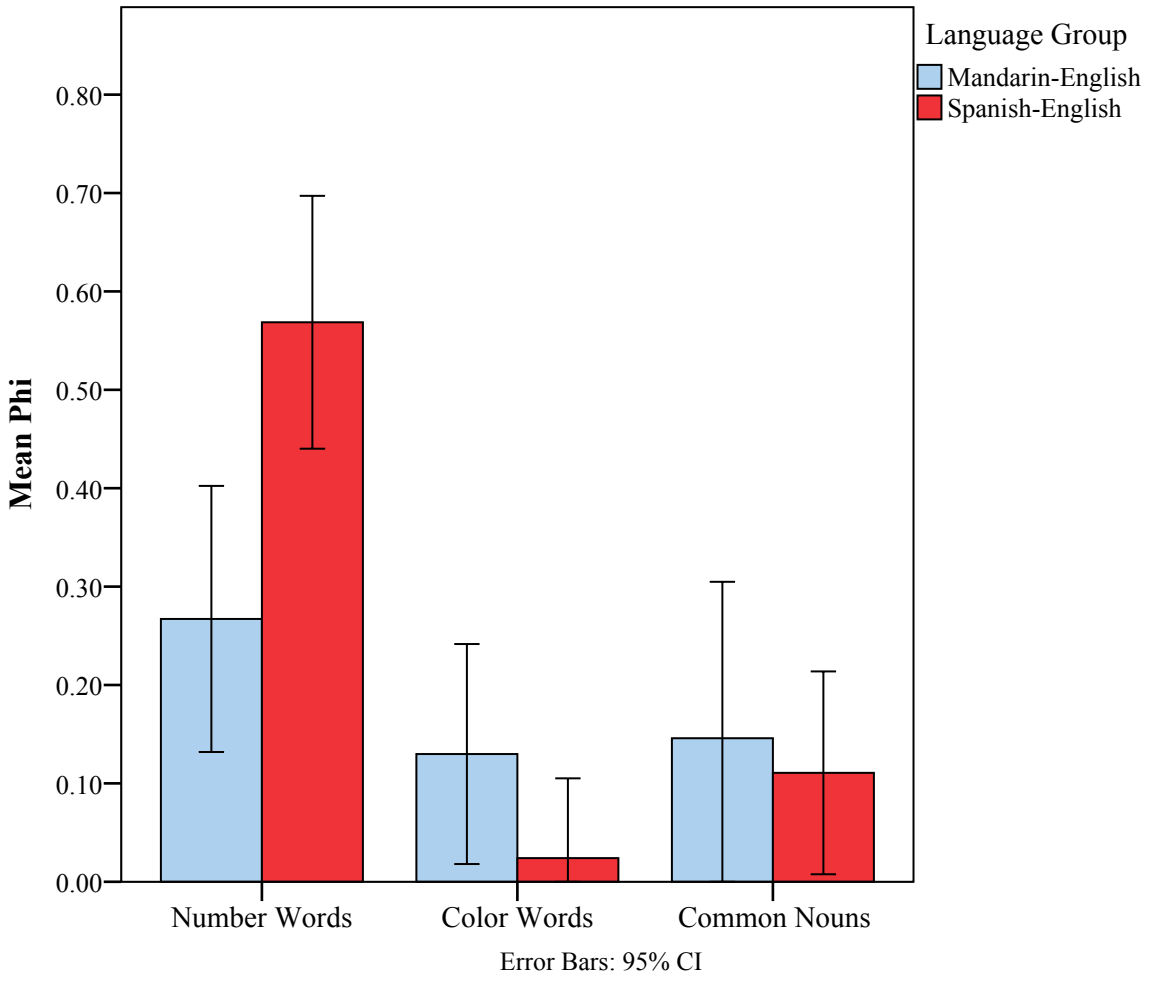

Figure 2.2. Mean phi values for the association between children's knowledge of number words, color words, and common nouns in English and their other language.

Counting Objects

This task measured children's ability to correctly count ten objects; thus, the maximum score possible was 10. For Mandarin-English bilinguals, in Mandarin, the mean score was 8.0 (SD = 3.073) and 63% performed at ceiling (i.e., counted the ten objects correctly); in English,

the mean score was 9.8 (SD = 0.894) and 95% performed at ceiling. For Spanish-English bilinguals, in Spanish, the mean score was 5.3 (SD = 2.983) and 17% performed at ceiling; in English, the mean score was 8.5 (SD = 2.751) and 70% performed at ceiling.

A two-way mixed ANOVA was conducted with counting score (English vs. other language) as the within-subjects factor and language group (Mandarin-English vs. Spanish-English bilinguals) as the between-subjects factor. There was a main effect of counting score, with participants performing better in English than in their other language, $F(1, 47) = 28.018$, $p < .001$. There was also a main effect of language group, with Mandarin-English bilinguals performing better than Spanish-English bilinguals, $F(1, 47) = 10.653$, $p = .002$. However, there was no interaction between counting score and language group, $F(1, 47) = 2.163$, $p = .148$.

Discussion

The purpose of the present study was to test Mandarin-English and Spanish-English bilingual preschoolers on their knowledge of number words, color words, and common nouns (words for animals and vehicles) to determine whether their knowledge of number words was more consistent across their two languages than their knowledge of other types of words. This study was motivated by Carey's (2009) conceptual-role bootstrapping account of number-concept acquisition, which predicts that learning the meanings of number words is essentially a process of filling in a placeholder structure provided by the count list. Therefore, for bilingual learners, as soon as the meaning of, say the third word in the count list of one of their languages is understood, it should be fairly easy for them to figure out what that third word means in the count list of their other language as well.

Interestingly, the results differed based on language group. For Spanish-English bilinguals, knowledge of number words was more highly correlated across their two languages

than knowledge of either color words or common nouns. However, for Mandarin-English bilinguals, this was not the case; the consistency of their knowledge of number words across their two languages did not differ significantly from that of the other word types. It is important to note that our data analysis did not measure participants' knowledge itself, only the consistency of their knowledge. Therefore, while Spanish-English bilinguals' knowledge of number words was more consistent than that of Mandarin-English bilinguals, our results should not be interpreted as meaning that Spanish-English bilinguals possessed more knowledge of number words than Mandarin-English bilinguals.

There may be several reasons for these differing results. It could be that Mandarin-English bilinguals lacked the prerequisite knowledge of the count lists of their languages. However, since we tested participants on the Counting Objects task, we know that this was not the case. In fact, Mandarin-English bilinguals performed significantly better than Spanish-English bilinguals on this task. This is actually what we would expect because the Mandarin-English bilinguals were from higher-income households than the Spanish-English bilinguals, and previous research (e.g., Jordan, Kaplan, Locuniak, & Ramineni, 2007; Jordan, Kaplan, Olah, & Locuniak, 2006) has shown that children from low-income backgrounds possess less knowledge of counting than their higher-income peers.

Another possibility is that linguistic differences between Mandarin and Spanish contributed to the differences observed between the two groups. In Mandarin, there are two different words for the number word "two": "èr" is used for counting and "liǎng" is used to talk about quantities of different things. For example, if you wanted to say "two books" in Mandarin, you would use "liǎng." Thus, the number words used for the count list in Mandarin do not map on exactly to the number words used to describe quantities. This could make it harder for

Mandarin learners to figure out the cardinal meaning of the number word "two." In addition, the prediction arising from Carey's number-concept acquisition account that number-word meanings should be easy to translate across two languages breaks down somewhat for Mandarin.

Number words may also be harder to learn in Mandarin than in English or Spanish because Mandarin is a classifier language, whereas English and Spanish are count/mass languages. Differences in the numerical syntax of classifier languages versus count/mass languages have been shown to lead to cross-linguistic differences in number-word learning. For example, Sarnecka and colleagues (2007) found that children learning English or Russian, which are both count/mass languages, learned the meanings of the number words "one," "two," and "three" faster than children learning Japanese, which is a classifier language. They concluded that singular/plural marking in a language helps children learn number words. Mandarin, like Japanese, has little numerical syntax: it does not have singular/plural marking, and a classifier is required to combine nouns and number words. These linguistic characteristics actually delay number-word learning by three to six months for monolingual Mandarin speakers, compared to monolingual English speakers (Le Corre, Li, Huang, Jia, & Carey, under revision). Thus, it is possible that Mandarin-English bilinguals' knowledge of number words in Mandarin was behind their knowledge of number words in English, leading to inconsistent knowledge across their two languages.

Finally, the divergent findings between Mandarin-English and Spanish-English bilinguals may simply be a sample size issue. It could be that we just need to test more Mandarin-English bilinguals to see an effect. A power analysis revealed that in order to detect a medium effect size (.3) between language groups, at 80% power, with a significance level of $p < .05$, and a repeated measures correlation of .5, we need 27 participants in each group. Although we included 30

Spanish-English bilinguals in the data analysis, we were only able to include 20 Mandarin-English bilinguals. Therefore, it is possible that testing more Mandarin-English bilinguals could change our results. Note that the lower number of Mandarin-English than Spanish-English bilinguals included in the data analysis was not for lack of trying. Remember that we tested an additional 21 Mandarin-English bilinguals; however, they were too advanced for the study (as indicated by their perfect performance on all trials of one or more word types in both languages).

In sum, Carey's (2009) proposal that number-word learning *is* number-concept creation was only partially supported by our results: We found that knowledge of number words was more consistent across languages than knowledge of color words and common nouns for Spanish-English bilinguals, but not for Mandarin-English bilinguals. The may be a real phenomenon or could purely be a sample size problem. Future research should include more participants and another bilingual comparison group learning a classifier language (e.g., Japanese-English bilinguals) to clarify these results.

CHAPTER THREE: Numerical Knowledge of Low-Income Bilingual Preschoolers: A Descriptive Study

Of all the knowledge acquired before kindergarten, early math concepts may be the most important prerequisite to later school success. In a recent meta-analysis of six large longitudinal datasets from the U.S., Canada, and Great Britain, Duncan and colleagues (2007) found that pre-kindergarten math skills were the single best predictor not only of later math performance but of later academic performance overall. In fact, early math skills, particularly knowledge of numbers and ordinality, were more predictive than early reading or attention skills. Furthermore, the relationship between early math and later academic success was found for children from both low and high socioeconomic backgrounds.

Yet, children enter school with varying degrees of math knowledge (Siegler, 2009), due in part to socioeconomic status (SES). SES-related differences in math knowledge are present in preschool and widen over the years, resulting in lower mathematics achievement throughout elementary school and high school among children from low-income families (Clements & Sarama, 2007; Starkey, Klein & Wakely, 2004). Low-income children come to kindergarten with significantly less knowledge of counting, numbers, and number operations than middle-income children (Jordan, Kaplan, Locuniak, & Ramineni, 2007; Jordan, Kaplan, Olah, & Locuniak, 2006). In fact, low-income children enter kindergarten far behind their higher-income peers on a wide range of foundational math tasks. These tasks include counting out loud, counting a set of objects, cardinality, identifying written numerals, adding and subtracting, comparing numerical magnitudes, and number line estimation (Ginsburg & Russell, 1981; Griffin, Case, & Siegler, 1994; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Jordan, Kaplan, Olah, & Locuniak, 2006; Jordan, Huttenlocher, & Levine, 1992; Jordan & Levine, 2009; Jordan, Levine, & Huttenlocher,

1994; Kirk, Hunt, & Volkmar, 1975; Saxe, Guberman, & Gearhart, 1987; Siegler, 2009; Starkey, Klein, & Wakeley, 2004). Moreover, low-income children have fewer number-related experiences at home and in their preschools than their middle-income peers, which leads to less math knowledge at the start of kindergarten (Clements & Sarama, 2007).

In addition to SES, language is another critical factor in early number development, yet its role is largely unstudied. Young children acquire exact-number concepts through the medium of language, and their first symbols for exact numbers are the cardinal number words of their native language (Carey, 2004; Carey & Sarnecka, 2006; Spelke & Tsivkin, 2001). Recent work by Negen and Sarnecka (2012) has shown that number-word knowledge in 2-4-year-olds is strongly correlated with the child's vocabulary. Language environment also appears to impact number development; children in Japan, Taiwan, Russia and the U.S. show different patterns of number-concept acquisition, which seems to be associated with the languages they speak (Barner et al., 2009; Le Corre et al., 2003; Li et al., 2003; Sarnecka et al., 2007).

Therefore, another potential source of the disparity in early math skills among children may be language status. While various studies have looked at numerical knowledge in monolingual preschoolers (e.g., Dowker, 2008; Gelman & Gallistel, 1978; Ginsburg & Russell, 1981; Le Corre & Carey, 2007; Ramani & Siegler, 2011; Sarnecka & Lee, 2009; Wynn, 1992), few have done so in bilinguals. One of the only studies to consider the early math skills of bilingual preschoolers was recent work by Xue, Atkins-Burnett, and Moiduddin (2012). The researchers used the Applied Problems test, a measure of mathematical problem solving, from the Woodcock Johnson III Tests of Academic Achievement (WJ III ACH) to assess 675 Spanish-English bilingual preschoolers from Los Angeles Universal Preschool (LAUP) as part of the Universal Preschool Child Outcomes Study (UPCOS). Results revealed that participants' scores

were below the national average as compared to same-aged peers. However, another relevant study conducted by Iglesias (2012) found that 132 Spanish-English bilinguals attending Head Start programs in Florida demonstrated skills on the Applied Problems test that were on par with national age-based monolingual norms in English and Spanish. Results also revealed that children's performance did not differ significantly in Spanish versus English. Given these discrepancies and the scarcity of research in this area, more work is greatly needed to understand the impact that bilingualism may have on early math skills.

Because numerical cognition plays a significant role in early mathematics learning (Jordan & Levine, 2009), it is important to examine the influence that growing up bilingual may have. The number of children in the United States learning more than one language has increased dramatically, and a significant portion are exposed to Spanish at home (Páez, Tabors, & López, 2007). In fact, Latino students make up the fastest growing population. Furthermore, over half of Head Start children in California come from homes where Spanish is the primary language (California Head Start Association, 2011). Given the increasing numbers of bilingual children, particularly Spanish-English bilinguals, it is imperative to expand our understanding of math development in this population.

The present study was exploratory in nature and sought to describe the numerical knowledge of low-income Spanish-English bilingual preschoolers, a population that has been greatly understudied. This study consisted of two parts: an examination of whether low-income Spanish-English bilinguals' performance depended on the language of testing, and a comparison of low-income Spanish-English bilinguals to higher-income bilinguals, low-income monolinguals, and higher-income monolinguals. Participants were administered a vocabulary measure and a battery of numerical tasks. Our battery, while not exhaustive, assessed various

early math skills relevant to this age group. It included several verbal or symbolic number tasks (counting out loud, counting a set of objects, cardinality, identifying written numerals, and number line estimation), as well as a nonverbal or nonsymbolic numerical discrimination task.

Method

Participants

Participants included 123 low-income bilinguals with a mean age of 4 years, 7 months (*SD* = 4.5 months, range = 3;5 to 5;6), 44 higher-income bilinguals with a mean age of 4 years, 5 months (*SD* = 6.3 months, range = 3;7 to 5;6), 32 low-income monolinguals with a mean age of 4 years, 5 months (*SD* = 6.4 months, range = 3;5 to 5;3), and 42 higher-income monolinguals with a mean age of 4 years, 4 months (*SD* = 6.8 months, range = 3;5 to 5;5).

Low-income participants were recruited from Head Start programs and higher-income participants were recruited from private or university-affiliated preschools, all in southern California. English was the language of instruction at all of the preschools. At the time of recruitment, parents filled out a demographic form asking them about their child's language status (i.e., the percent of time the child was exposed to English and/or another language at home), household income, and parent education level. Low-income bilinguals were all exposed to Spanish and English. They were exposed to Spanish at home 76% of the time, on average. Higher-income bilinguals were exposed to a variety of different languages other than English: Mandarin (n=15), Chinese (n=8), Cantonese (n=5), Farsi (n=4), Korean (n=4), Bengali (n=1), Bulgarian (n=1), French (n=1), Gujarati (n=1), Hindi (n=1), Russian (n=1), Tamil (n=1), and Ukrainian (n=1). They were exposed to a language other than English 65% of the time, on average. Table 3.1 provides a break down of household income and parent education level information as a percentage of children in each group. Families received a prize (e.g., a small

stuffed animal) when they signed up to participate in the study; no prizes were given at the time of testing.

Table 3.1

Family Characteristics as a Percentage of Group Membership

	Bilinguals		Monolinguals	
Characteristic	Low	Higher	Low	Higher
Income				
Under $10,000	29.3		28.1	
$10 – $15,000	24.4		15.6	
$15 – $20,000	24.4		15.6	
$20 – $30,000	17.1		28.1	
$30 – $40,000	4.9		12.5	
$75,000 +		100.0		100.0
Parent Education				
Less than H.S. diploma	53.7			
H.S. diploma/G.E.D.	26.8		34.4	
Technical/Trade school	1.6		9.4	
Some college	6.5		31.3	2.4
College degree	4.1	22.7	15.6	4.8
Post-college education		68.2		85.7
No response	7.3	9.1	9.4	7.1

Procedure

Children were administered a vocabulary measure and a battery of numerical tasks to assess their mathematical knowledge. They met individually with an experimenter in a parent education room or hallway near their classroom for three 20-minute sessions over the course of a week. For the low-income bilinguals, the vocabulary measure and symbolic number tasks were administered in both Spanish and English, and the language that was administered first was

counterbalanced between participants; the nonsymbolic numerical discrimination task was administered in either Spanish or English, whichever the child preferred. For the higher-income children, the tasks were only administered in English. Experimenters were undergraduate research assistants who were fluent in both Spanish and English.

Measures

Peabody Picture Vocabulary Test (PPVT–III). All children were given the PPVT–III (Dunn & Dunn, 1997) to assess their English receptive vocabulary. Children were shown four pictures, and asked to point to the picture that corresponded to the word spoken by the experimenter. The PPVT-III has a mean standard score of 100 and a standard deviation of 15. It was standardized on a monolingual, English-speaking sample of children from the United States.

Test de Vocabulario en Imagenes Peabody (TVIP). Low-income bilinguals were given the TVIP (Dunn, Lugo, Padilla, & Dunn, 1986) to assess their Spanish receptive vocabulary. It is similar in presentation and administration to the PPVT-III. The TVIP has a mean standard score of 100 and a standard deviation of 15. It was standardized on monolingual, Spanish-speaking samples of children from Mexico and Puerto Rico. According to Dunn et al. (1986), the test is appropriate for measuring Spanish vocabulary growth in both monolingual and bilingual Spanish children.

Counting Out Loud. Children were asked to count out loud from one through ten to assess their knowledge of the counting sequence. The experimenter introduced the task by saying, "Let's count to ten. One, two, three, four, five, six, seven, eight, nine, ten. Good! Now *you* count." Children were asked to count twice by themselves. Counting was coded as correct up to the point of the first error, and children's highest correct count was used in the analysis.

Counting Objects. Children were asked to count six objects on a laminated card to assess their knowledge of one-to-one correspondence. The experimenter asked children to count the objects by saying, "Can you show me how you count these?" When children were reluctant to count, they were encouraged to do so by the experimenter. For example, if a child did not start counting on her own, the experimenter pointed to the leftmost object, said the first number word, and then pointed to the next object. If a child stopped counting before reaching the sixth number word, the experimenter repeated the last two number words the child had said with a rising intonation (e.g., "three, four…?"); or, the experimenter asked, "What comes after N?" (where N is the last number word produced by the child). If the child still did not continue counting, her counting sequence was considered to end at the last number word she produced. Children were asked to count twice. Counting was coded as correct up to the point of the first error, and children's highest correct count was used in the analysis.

Give-A-Number (Give-N). The Give-N task (Wynn, 1990, 1992) was used to place children into number-knower levels based on their understanding of exact-number concepts. Children's performance on this task determined their knower level (i.e., pre-knower, one-knower, two-knower, three-knower, four-knower, and cardinal principle or CP-knower). In this task, children were asked to give a certain number of objects between one and six to a stuffed animal. They were asked for each number (1-6) three times in a preset, randomized order for a total of 18 trials. The experimenter set up the task by placing the following items on a table: a stuffed animal (e.g., a tiger), a tub with small, plastic objects in it (e.g., yellow bananas), and a lid from the top of the tub (used as a plate). The experimenter introduced the game by saying, "This is the tiger's plate. In this game, you are going to give something to the tiger. I'll tell you what to give him and you put it on the plate and slide it over to him, like this." (Experimenter

pretends to put an object from the tub on the lid and then slides it over to the stuffed animal.) Then, the experimenter asked the child, "Can you the tiger *one* banana?" Once the child slid the lid with the banana on it over to the tiger, the experimenter asked, "Is that *one*?" Children were given generalized positive feedback (e.g., "thank you!") on every trial, regardless of their responses. Children's responses were scored using an excel sheet developed by Negen, Sarnecka, and Lee (2011) that was designed to infer children's knower levels from Give-N data.

Numeral Identification. Children were asked to identify the written numerals one through ten. The experimenter set up the task by placing a foam board house with a Velcro square in the middle of it on the table and a set of laminated cards each with a written number ranging from zero to ten in a pile next to the house, such that the numbers were all visible but were not in numerical order. The experimenter introduced the game by saying, "Here are some numbers. I'm going to look for zero. This is zero. (Experimenter shows the laminated card with the number zero on it to the child.) I'm going to put zero in its home, like this. (Experimenter places the number on the Velcro square in the house and then puts it back in the pile.) Now it's your turn. Can you find the number *one* and put it in its home?" Once the child put a number on the Velcro square in the house, the experimenter asked, "Is that *one*?" Children were asked for the numbers one through ten in numerical order and were given generalized positive feedback (e.g., "thank you!") on every trial, regardless of their responses. Numeral identification was coded as correct or incorrect, based on children's responses.

Scaffolded Number Line. Children were asked to place the numbers one through nine (excluding five) on a number line. The experimenter set up the task by placing a foam board number line with the numbers zero and ten on it, and nine Velcro squares for the other numbers in between. The experimenter also put a set of laminated cards (the same ones used in the

Numeral Identification task) with the numbers one through nine in a pile next to the number line. The experimenter introduced the game by saying, "This is a number line. It starts with zero and goes to ten. (Experimenter points to the zero and then the ten.) And, this is five. (Experimenter picks the laminated card with the number five out of the pile.) It goes right in the middle, like this. (Experimenter places the five on the fifth Velcro square of the number line.) Now it's your turn. I'll give you a number and you put it in its place on the number line. Okay, here's the number *seven*. Can you show me where it goes on the number line?" Children were asked for the numbers one through nine (excluding five, since that was used as an example) in a preset, randomized order. They were given generalized positive feedback (e.g., "thank you!") on every trial, regardless of their responses. Children's responses were coded as correct or incorrect, based on whether they placed each number in the correct location on the number line.

Numerical Discrimination. For each trial of the numerical discrimination task, children were shown two side-by-side arrays, containing between 20 and 100 black dots each, on a 21.5 × 12.5 cm laminated card. Participants were first presented with training trials to ensure that they understood the task. For the training trials, there were three blocks at an easy ratio of 1:3 (=.33). The 1:3 ratio was used as training because previous research has shown that even preverbal infants can discriminate numbers at that ratio (Feigenson et al., 2004). The experimenter said to participants, "Look at this card. This card has two sides. There are some dots on this side, and some dots on this side. (Experimenter points to each side.) You need to point to the side that has *more* dots. Which side has *more* dots?" If participants picked the wrong side on the training trials, the experimenter explained why it was wrong to help cue them into the task-relevant dimension of number rather than area. For example, if participants chose the side with bigger dots when there were more dots on the side with smaller dots, the experimenter said: "Well these

dots are bigger, but *this* side has *more* dots. They're smaller, but there's *more* of them." To ensure that participants were not guessing, they had to answer eight training trials correct in a row before moving on to the test trials. (If necessary, trials were repeated in a cycle.) On the test trials, the experimenter asked, "Which side has more dots?" For the test trials, there were nine blocks with ratios at 1:2 (= .50), 7:12 (= .58), 2:3 (= .66), 17:24 (= .71), 3:4 (= .75), 4:5 (= .80), 5:6 (= .83), 7:8 (= .87), and 9:10 (= .90). There were eight trials per block, and all trials within each block contained the same ratio. Feedback was given after every trial (e.g., "That's right—this side has more" or "Uh oh, this side has more dots, you see"); however, participants were no longer told why their response was incorrect. Trials were presented too rapidly for children to count the dots, and no children were observed attempting to count.

Results

Spanish versus English Performance of Low-Income Bilingual Children

Vocabulary Measures. The PPVT and TVIP were used to measure children's receptive vocabulary in English and Spanish, respectively. On the PPVT, the mean standard score was 76.780 (*SD* = 16.557). On the TVIP, the mean standard score was 81.862 (*SD* = 16.102). Both of these mean standard scores fell outside the normal range—more than one standard deviation (*SD* = 15) away from the population mean (μ = 100). Low-income bilinguals scored significantly better on the TVIP than on the PPVT, $t(122) = -2.517$, $p = .013$.

Counting Out Loud. This task measured children's ability to correctly count out loud to ten; thus, the maximum score possible was 10. The average counting out loud score was 6.472 (*SD* = 3.225) in Spanish and 8.724 (*SD* = 2.571) in English. Children performed significantly better in English than Spanish, $t(122) = -8.509$, $p < .001$. While only 35% of children performed at ceiling (i.e., counted out loud correctly up to 10) in Spanish, 75% did so in English.

Counting Objects. This task measured children's ability to correctly count six objects; thus, the maximum score possible was 6. In Spanish, the mean score was 5.008 (*SD* = 1.711). In English, the mean score was 5.520 (*SD* = 1.210). Children performed significantly better in English than Spanish, $t(122) = -3.450$, $p = .001$. However, most children performed at ceiling (i.e., counted the six objects correctly) in both languages: 68% of children performed at ceiling in Spanish and 84% did so in English.

Give-N. This task measured children's knowledge of the exact meanings of the numbers "one" through "six," to determine their knower level in each of their languages; the highest knower level possible was CP-knower. When assessed in Spanish, there were 9 pre-knowers (7%), 29 one-knowers (24%), 37 two-knowers (30%), 26 three-knowers (21%), 6 four-knowers (5%), and 16 CP-knowers (13%). When assessed in English, there were 5 pre-knowers (4%), 36 one-knowers (29%), 25 two-knowers (20%), 22 three-knowers (18%), 7 four-knowers (6%), and 28 CP-knowers (23%). Children performed significantly better in English than Spanish, $t(122) = -3.308$, $p = .001$. There was a strong positive correlation between children's knower-level in Spanish and English, $r = .808$, $p < .001$; 62% of children performed equally in both languages, 27% performed better in English, and 11% performed better in Spanish.

Numeral Identification. This task measured children's ability to correctly identify the written numerals one through ten; thus, the maximum score possible was 10. The average numeral identification score was 3.415 (*SD* = 2.942) in Spanish and 4.309 (*SD* = 3.647) in English. Children performed significantly better in English than Spanish, $t(122) = -5.023$, $p < .001$. However, the most common score in both languages was a 1, with 20% of children receiving that score in Spanish and 20% of children receiving that score in English. This suggests that a cluster of children appear to simply be guessing (one would expect a score of 1 on average

from guessing). Yet, 14% of children performed at ceiling in English and only 5% did so in Spanish.

Scaffolded Number Line. This task measured children's ability to correctly place the numbers one through nine (excluding five) on a number line; thus, the maximum score possible was 8. In Spanish, the mean score was 1.951 (SD = 2.072). In English, the mean score was 2.000 (SD = 2.192). Children's performance in English versus Spanish did not differ significantly, $t(122) = -0.344$, $p = .731$. As with the Numeral Identification task, a significant portion of children appear to be guessing; the most common score in both languages was a 1 (one would expect a score of 1 on average from guessing), with 33% of children receiving that score in Spanish and 33% of children receiving that score in English.

Comparison of Bilingual/Monolingual Children from Low-/Higher-Income Households[4]

Peabody Picture Vocabulary Test (PPVT–III). The mean standard scores for each group were as follows: 76.780 (SD = 16.557) for low-income bilinguals, 98.455 (SD = 14.302) for higher-income bilinguals, 93.187 (SD = 14.410) for low-income monolinguals, and 110.048 (SD = 10.892) for higher-income monolinguals. Aside from the low-income bilinguals, the mean standard scores for the other three groups fell within the normal range of one standard deviation (SD = 15) for the population mean (μ = 100).

Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANOVA. There was a main effect of language group, with monolinguals performing better than bilinguals, $F(1, 237) = 40.394$, $p < .001$. There was also a main effect of income, with higher-income children performing better than low-income children,

[4] Since low-income bilinguals were tested in both Spanish and English on the symbolic number tasks, their highest score was used in this analysis.

$F(1, 237) = 76.506$, $p < .001$ (see Figure 3.1). However, there was no interaction between language group and income, $F(1, 237) = 1.194$, $p = .276$.

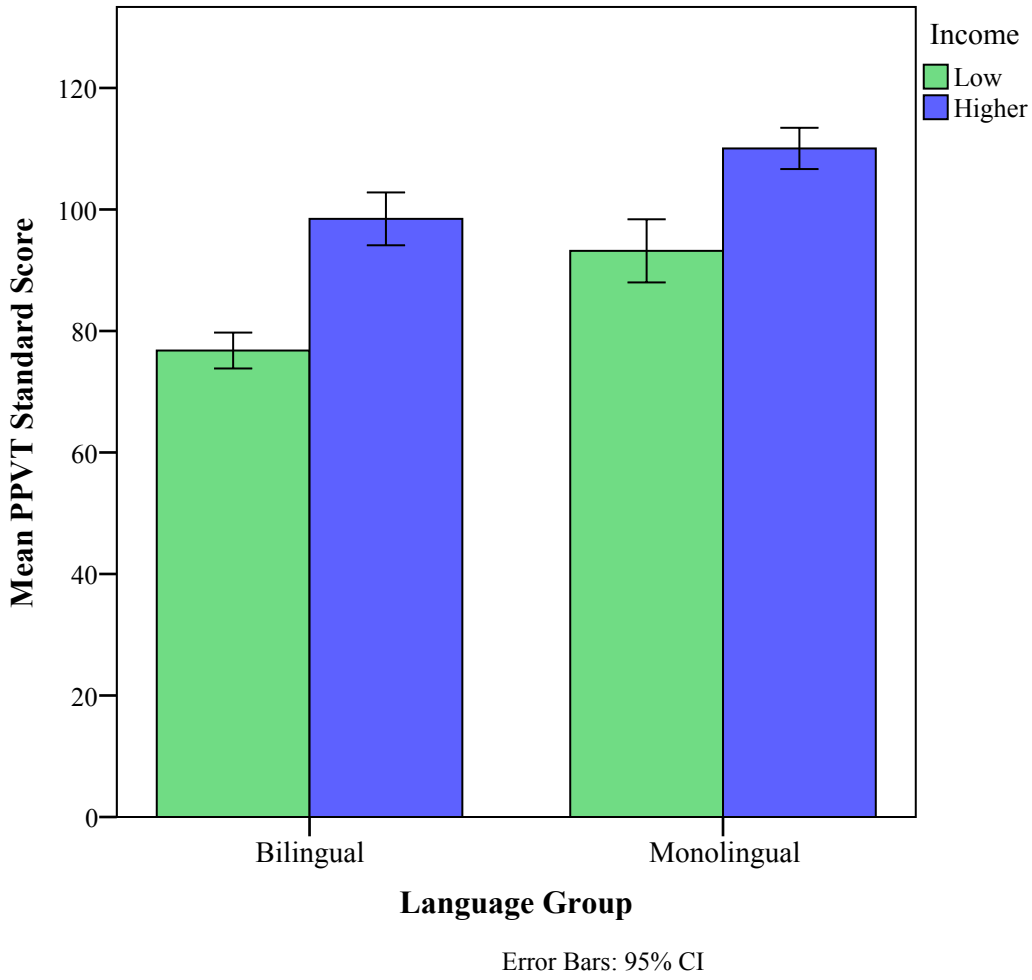

Figure 3.1. Mean PPVT standard scores by language group and income.

Counting Out Loud. Figure 3.2a shows the distribution of scores for each group. As this figure illustrates, the overwhelming majority of higher-income children and many of the low-income children performed at ceiling (i.e., counted out loud correctly up to 10). Specifically, 76% of low-income bilinguals, 100% of higher-income bilinguals, 63% of low-income monolinguals, and 98% of higher-income monolinguals performed perfectly on this task.

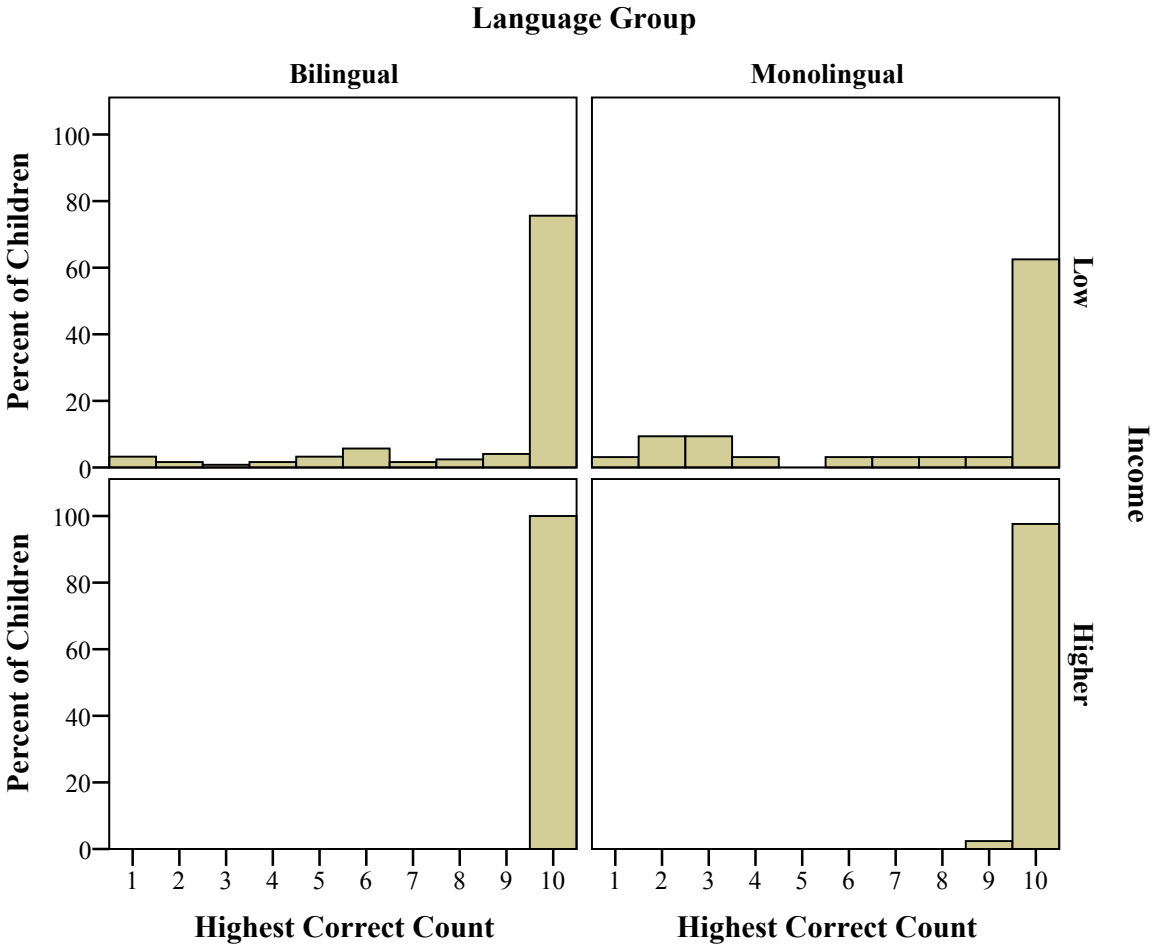

Figure 3.2a. Distribution of counting out loud scores for each group.

Table 3.2 provides the means and standard deviations separated out by group membership for all of the numerical tasks. Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 236) = 34.219$, $p < .001$ (see Figure 3.2b). This represents ceiling performance. There was also a significant effect of age, $F(1, 236) = 10.121$, $p = .002$. However, there was no main effect of language group, $F(1, 236) = 1.905$, $p = .169$, nor an interaction, $F(1, 236) = 2.767$, $p = .098$.

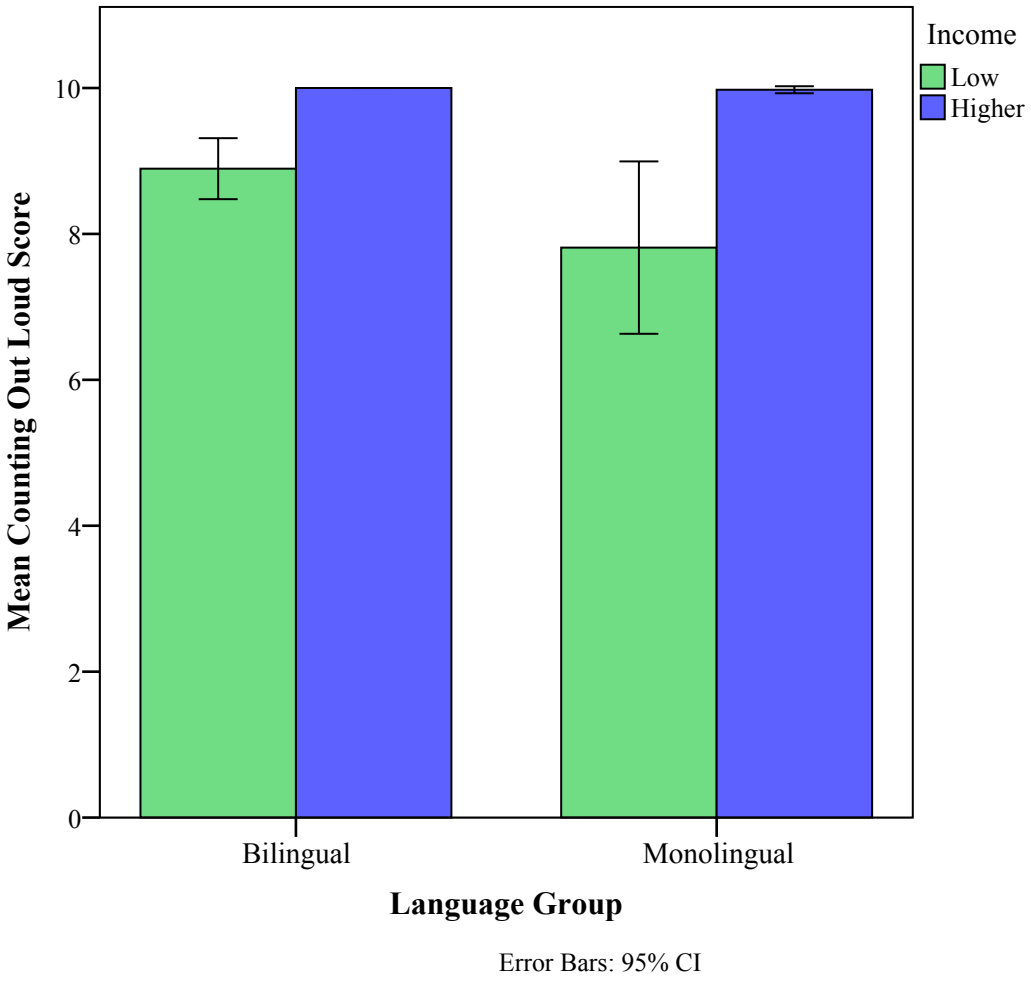

Figure 3.2b. Mean counting out loud scores by language group and income.

Counting Objects. Similar to the counting out loud task, most of the children performed at ceiling (i.e., counted the six objects correctly). Specifically, 89% of low-income bilinguals, 98% of higher-income bilinguals, 72% of low-income monolinguals, and 95% of higher-income monolinguals performed perfectly (see Figure 3.3a).

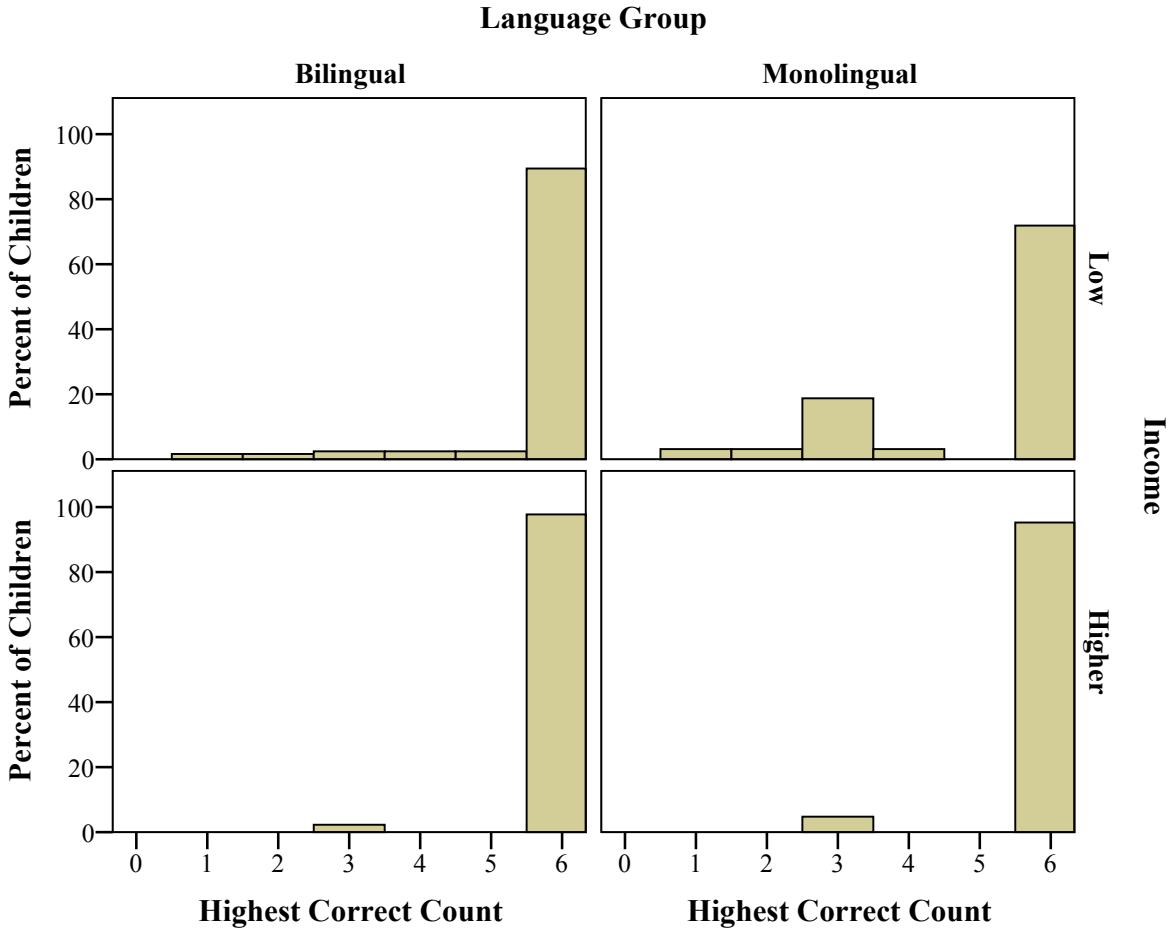

Figure 3.3a. Distribution of counting objects scores for each group.

Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 236) = 15.290$, $p < .001$. There was also a main effect of language group, with bilinguals performing better than monolinguals, $F(1, 236) = 4.314$, $p = .039$ (see Figure 3.3b). Age had a significant effect, $F(1, 236) = 7.907$, $p = .005$. However, there was no interaction between language group and income, $F(1, 236) = 3.465$, $p = .064$.

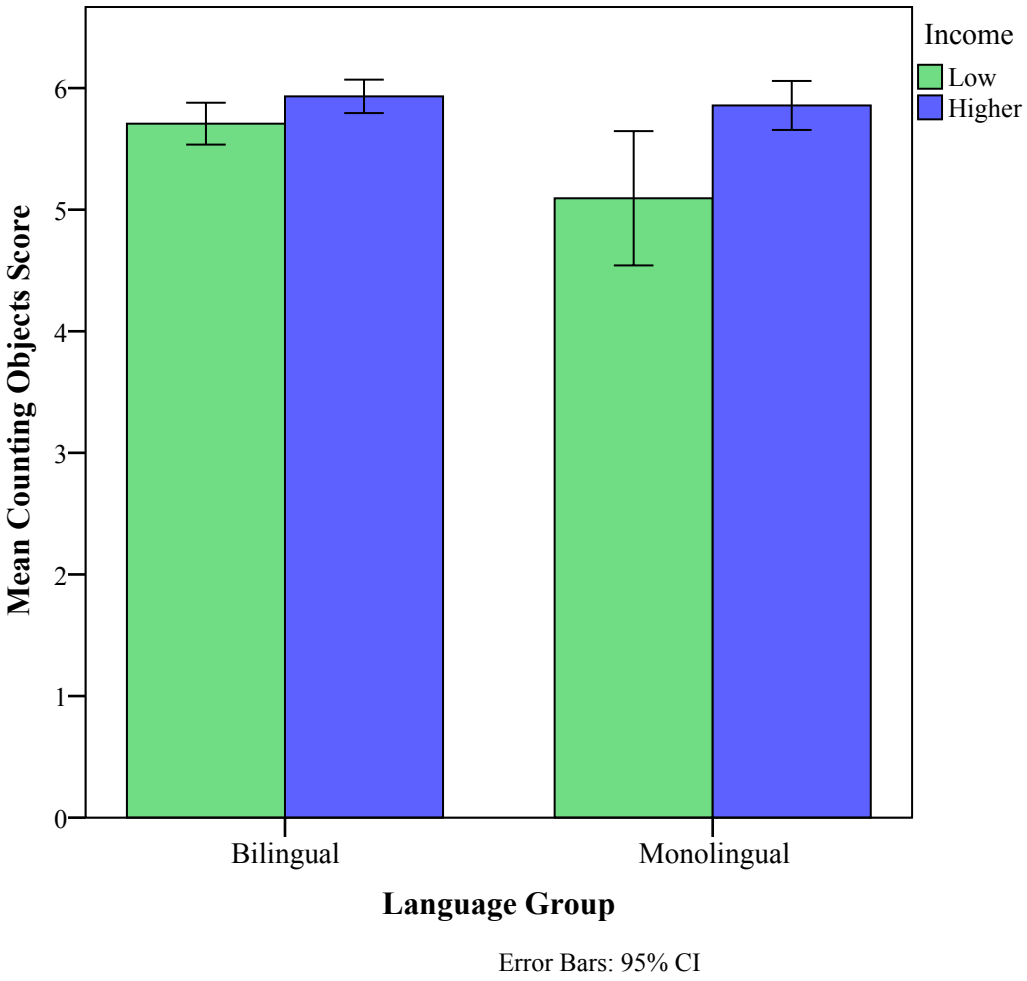

Figure 3.3b. Mean counting objects scores by language group and income.

Give-N. The majority of higher-income children (86% of higher-income bilinguals and 81% of higher-income monolinguals) performed at ceiling (i.e., understood the cardinality principle), whereas only some of the low-income children (24% of low-income bilinguals and 41% of low-income monolinguals) reached ceiling performance (see Figure 3.4a).

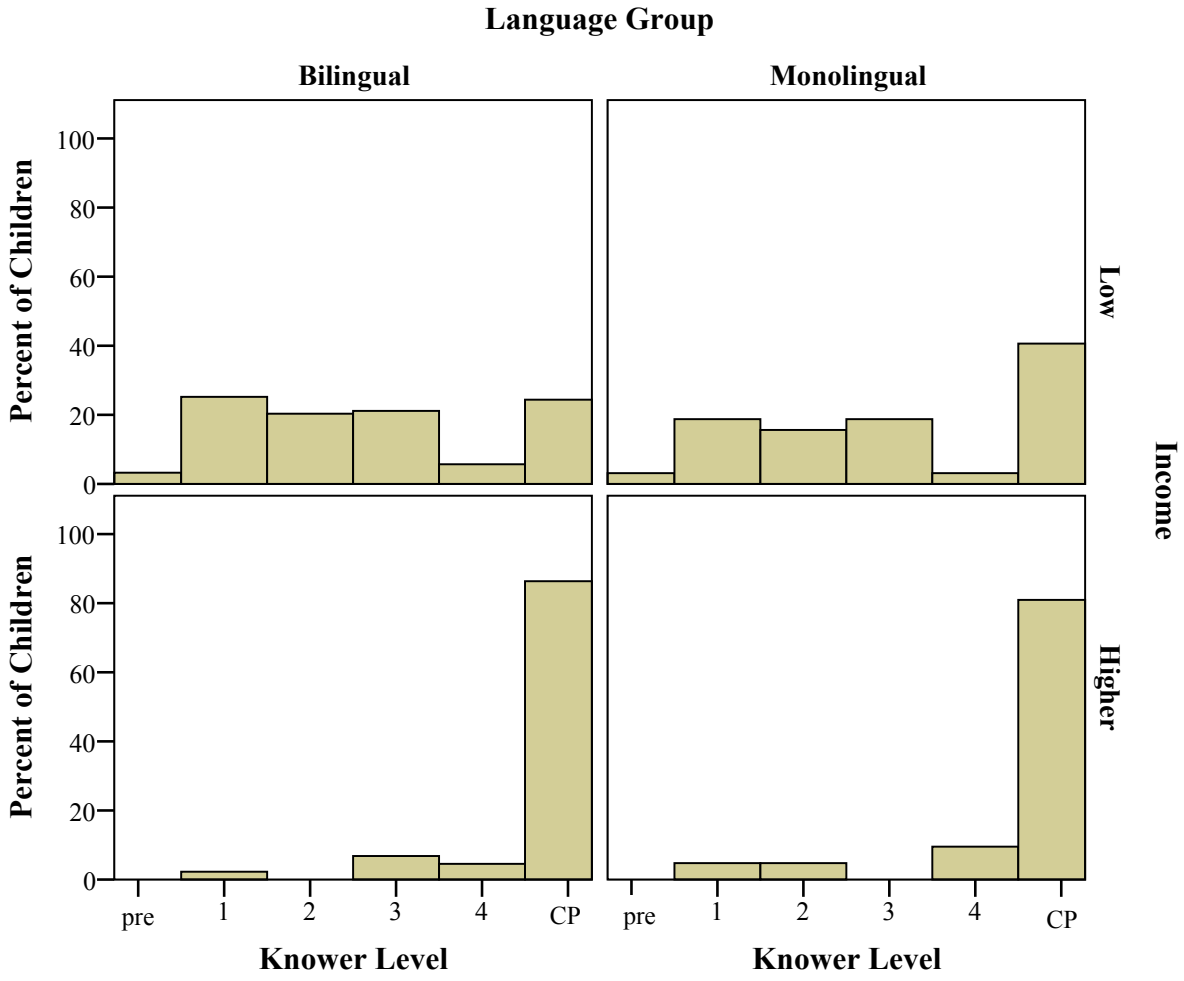

Figure 3.4a. Distribution of knower levels for each group.

Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 236) = 87.314$, $p < .001$ (see Figure 3.4b). This represents ceiling performance. There was also a significant effect of age, $F(1, 236) = 36.562$, $p < .001$. However, there was no main effect of language group, $F(1, 236) = 2.967$, $p = .086$, nor an interaction, $F(1, 236) = 3.566$, $p = .060$.

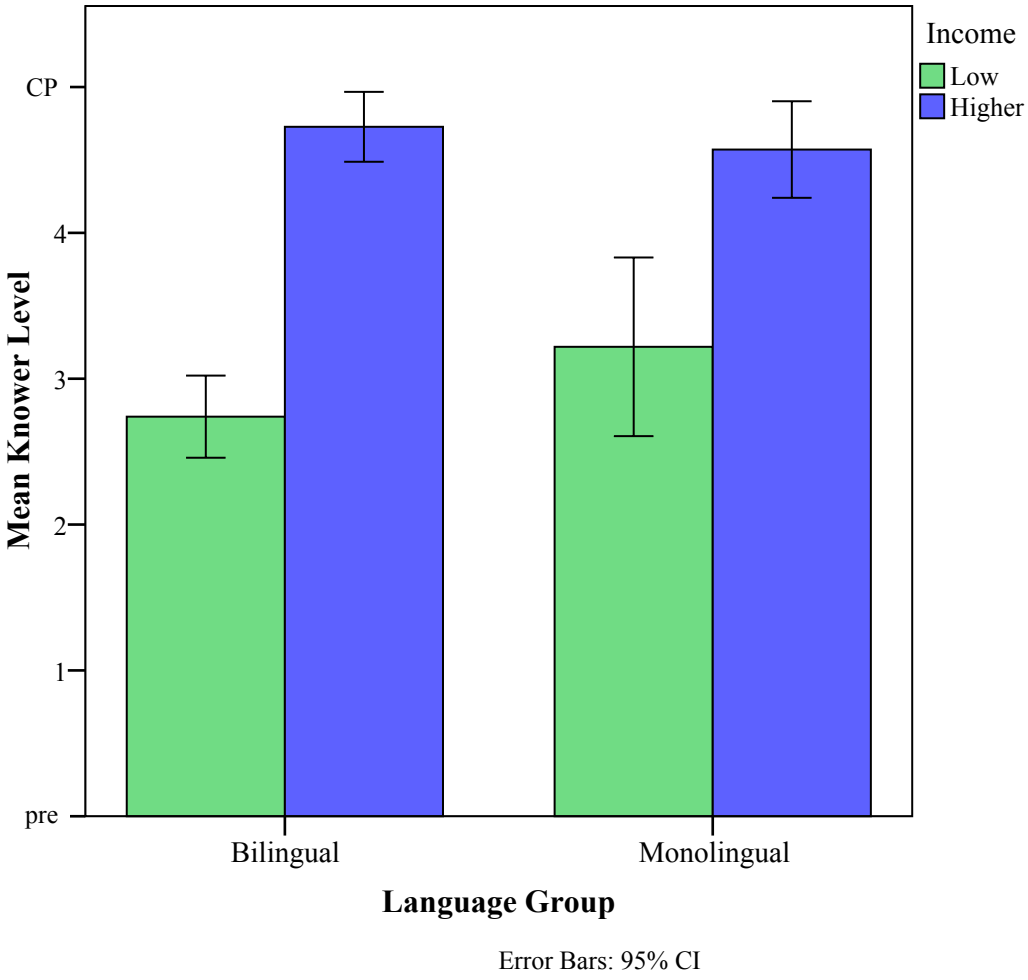

Figure 3.4b. Mean knower level by language group and income.

Numeral Identification. Many higher-income children (75% of higher-income bilinguals and 64% of higher-income monolinguals) performed at ceiling (i.e., correctly identified the written numerals one through ten), while far fewer low-income children (14% of low-income bilinguals and 19% of low-income monolinguals) reached ceiling performance (see Figure 3.5a).

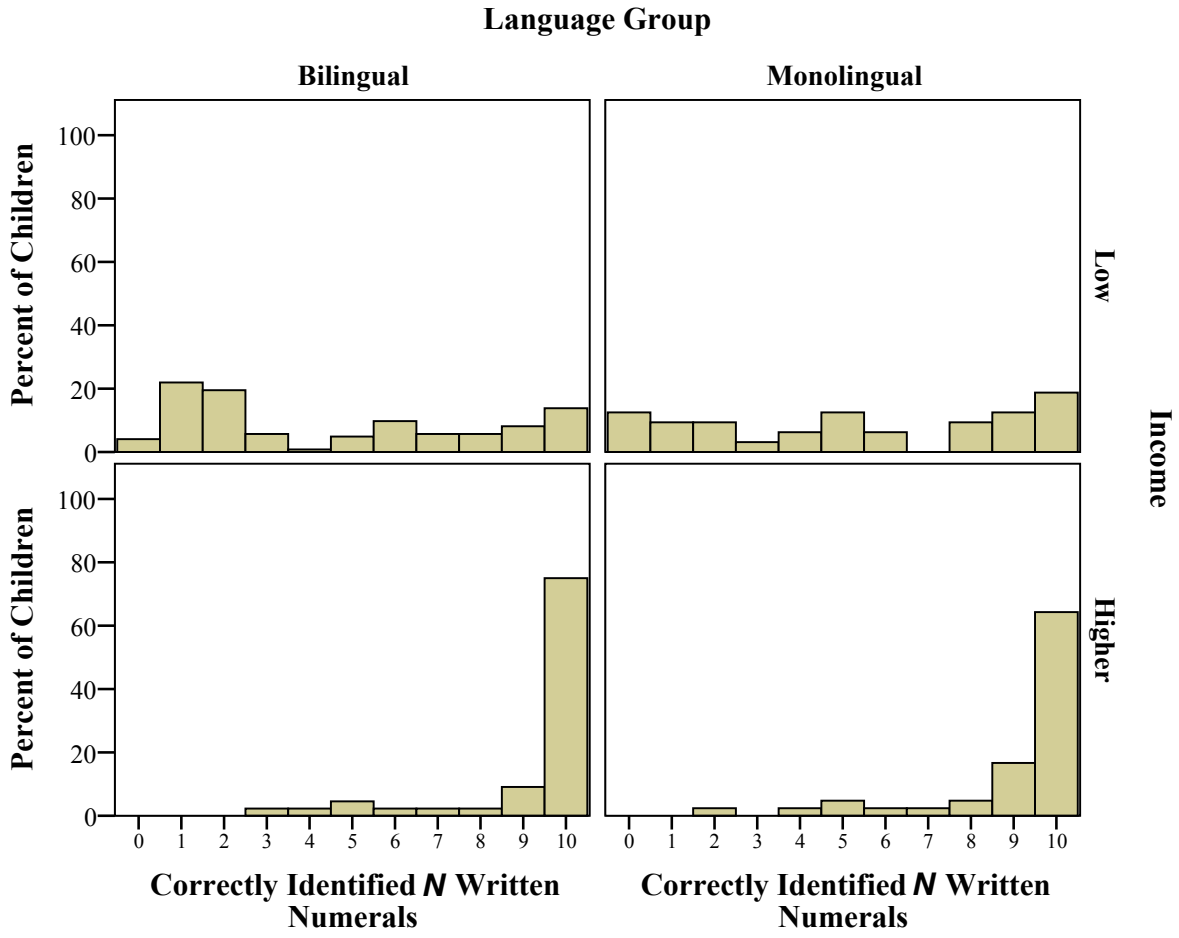

Figure 3.5a. Distribution of numeral identification scores for each group.

Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 236) = 104.938$, $p < .001$ (see Figure 3.5b). Age also had a significant effect, $F(1, 236) = 26.897$, $p < .001$. However, there was no main effect of language group, $F(1, 236) = 2.093$, $p = .149$, nor an interaction, $F(1, 236) = 1.748$, $p = .187$.

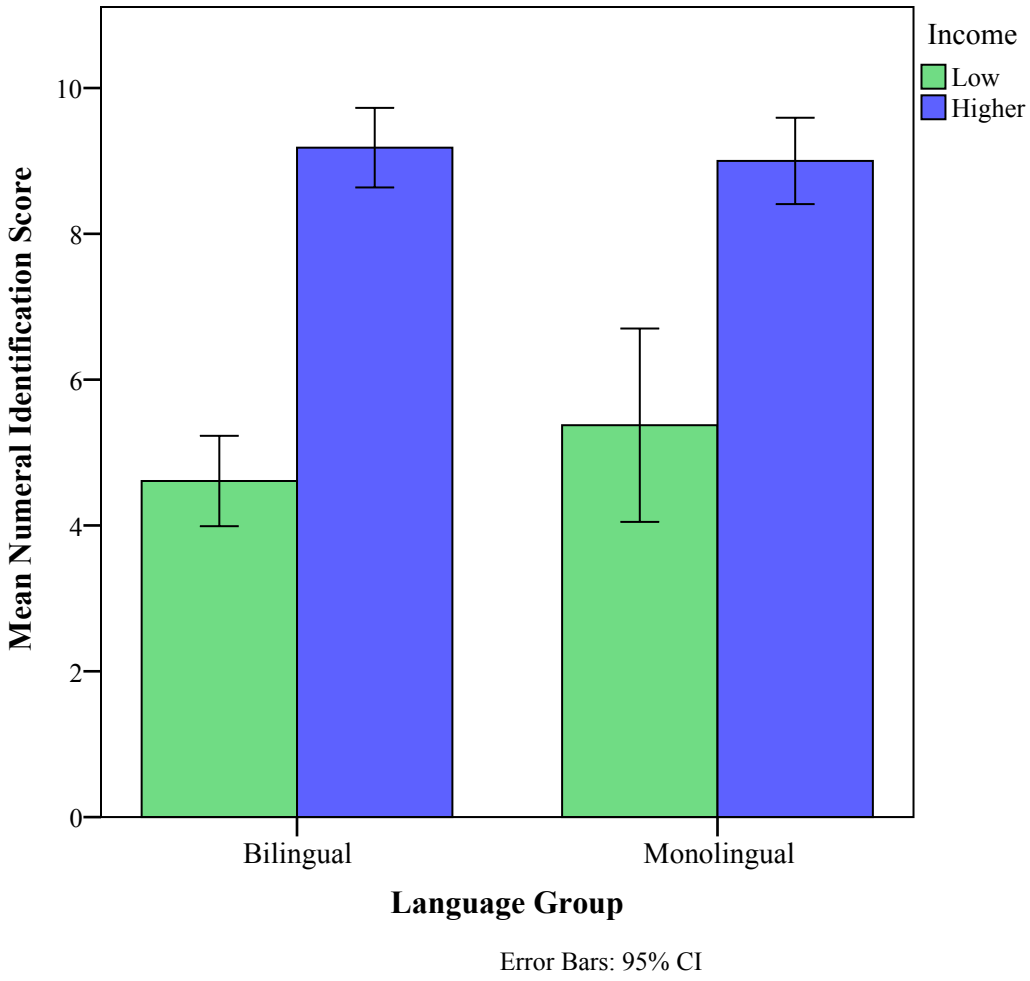

Figure 3.5b. Mean numeral identification scores by language group and income.

Scaffolded Number Line. As figure 3.6a shows, this was a challenging task for most children; only 4% of low-income bilinguals, 6% of low-income monolinguals, 31% of higher-income monolinguals, and 52% of higher-income bilinguals performed at ceiling (i.e., correctly placed the numbers one through nine [excluding five] on a number line).

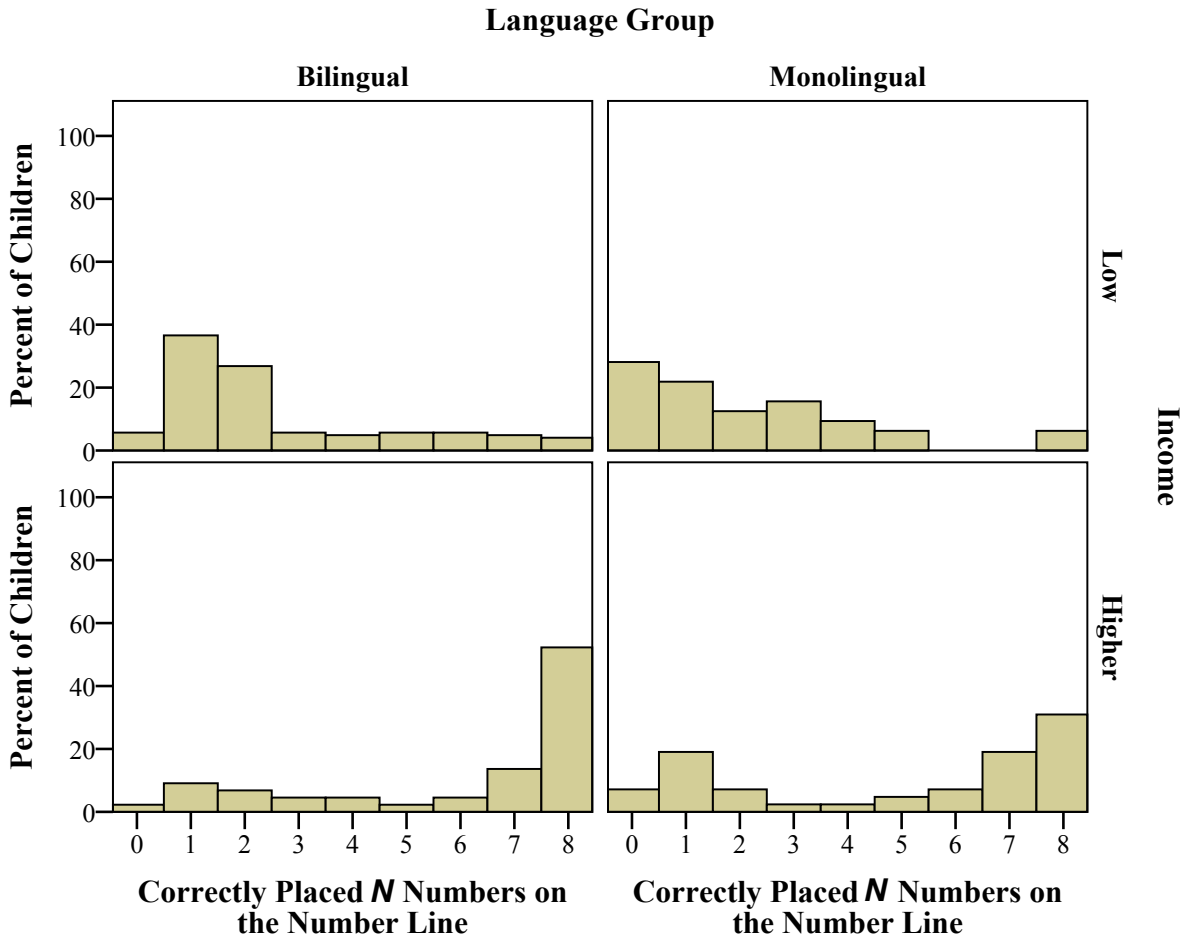

Figure 3.6a. Distribution of scaffolded number line scores for each group.

Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 236) = 117.677$, $p < .001$ (see Figure 3.6b). There was also a significant effect of age, $F(1, 236) = 64.721$, $p < .001$. However, there was no main effect of language group, $F(1, 236) = 1.425$, $p = .234$, nor an interaction, $F(1, 236) = 1.800$, $p = .181$.

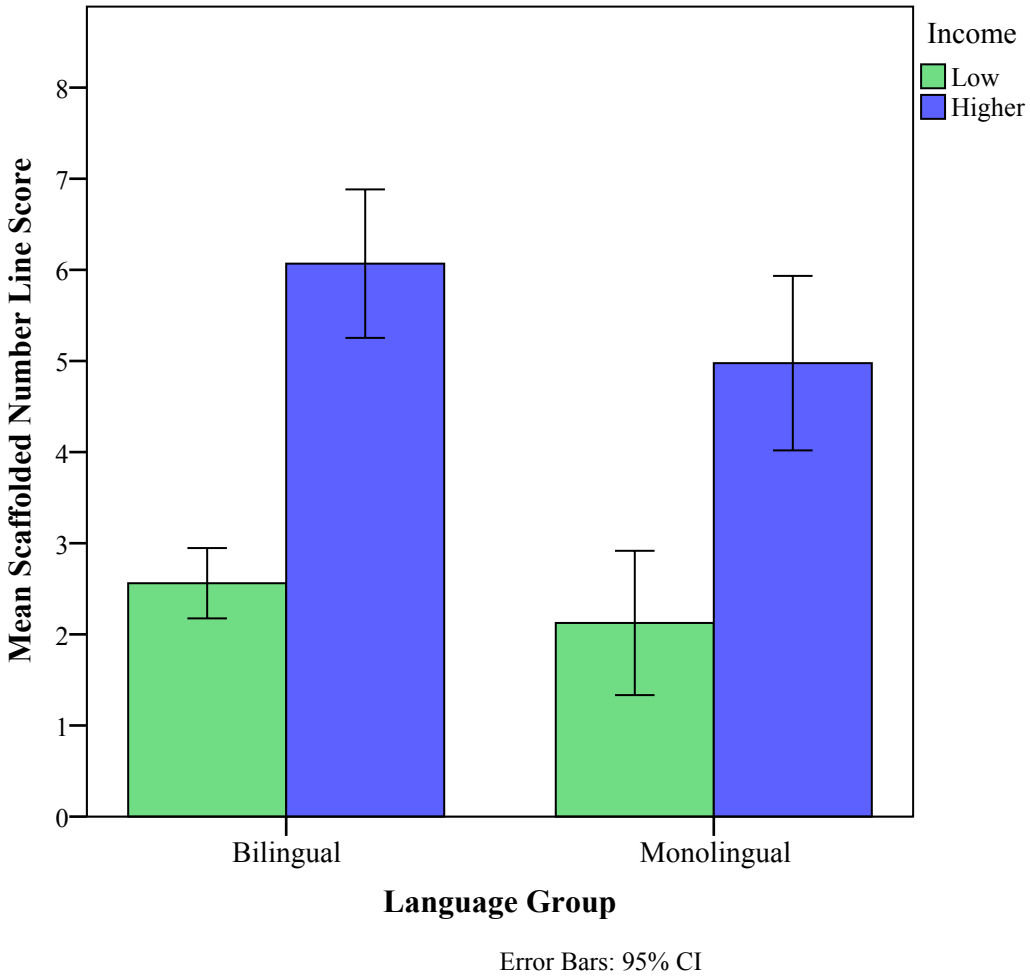

Figure 3.6b. Mean scaffolded number line scores by language group and income.

Numerical Discrimination. Of all participants, 76 low-income bilinguals, 38 higher-income bilinguals, 21 low-income monolinguals, and 37 higher-income monolinguals successfully completed this task. Seventy-seven children (36 low-income bilinguals, 2 higher-income bilinguals, 9 low-income monolinguals, and 3 higher-income monolinguals) were excluded from the data analysis because they did not complete the training trials. An additional 19 children (11 low-income bilinguals, 4 higher-income bilinguals, 2 low-income monolinguals,

and 2 higher-income monolinguals) were excluded for not performing significantly above chance (56%) on any of the test trials.

Mean proportion correct on both congruent and incongruent trials was used to assess overall performance. Data were analyzed with a 2 (Language Group; Bilinguals vs. Monolinguals) × 2 (Income; Low vs. Higher) ANCOVA with age as a covariate. There was a main effect of income, with higher-income children performing better, $F(1, 167) = 14.124$, $p < .001$ (see Figure 3.7). Age also had a significant effect, $F(1, 167) = 27.250$, $p < .001$. However, there was no main effect of language group, $F(1, 167) = 1.591$, $p = .209$, nor an interaction, $F(1, 167) = 1.100$, $p = .296$.

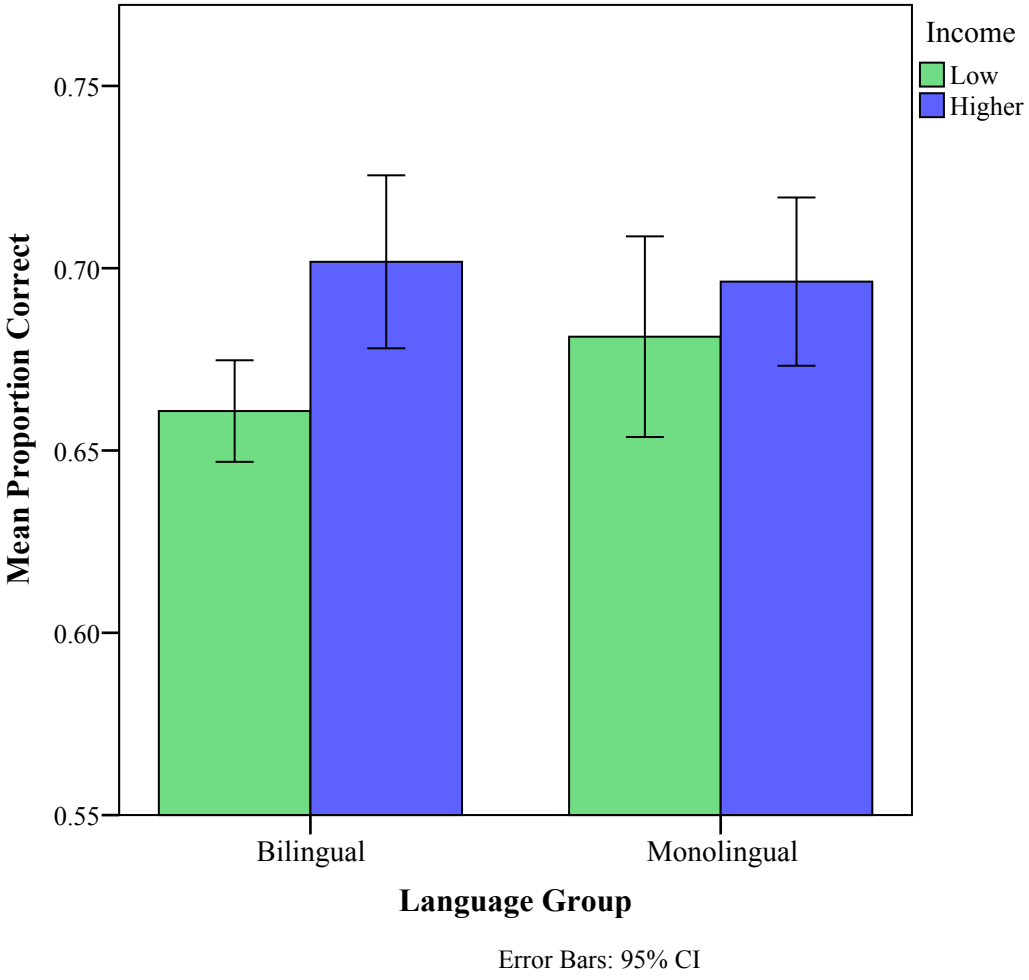

Figure 3.7. Mean proportion correct on both congruent and incongruent trials of the numerical discrimination task by language group and income.

Table 3.2

Means (SDs) for Numerical Tasks by Group Membership

	Bilinguals		Monolinguals	
Task	Low	Higher	Low	Higher
Counting Out Loud	8.89 (2.34)	10.00 (0.00)	7.81 (3.28)	9.98 (0.15)
Counting Objects	5.71 (0.96)	5.93 (0.45)	5.09 (1.53)	5.86 (0.65)
Give-N	2.70 (1.58)	4.73 (0.79)	3.22 (1.70)	4.57 (1.06)
Numeral Identification	4.61 (3.47)	9.18 (1.80)	5.38 (3.68)	9.00 (1.90)
Scaffolded Number Line	2.56 (2.16)	6.07 (2.68)	2.13 (2.20)	4.98 (3.07)
Numerical Discrimination	0.66 (0.06)	0.70 (0.07)	0.68 (0.06)	0.70 (0.07)

Discussion

The purpose of the present study was to describe the early math skills of low-income Spanish-English bilingual preschoolers by examining their performance in Spanish versus English, and by comparing their performance to that of higher-income bilinguals, low-income monolinguals, and higher-income monolinguals.

To investigate whether low-income Spanish-English bilinguals' performance depended on the language of testing, they were assessed in both languages on the vocabulary measure and symbolic number tasks. Participants scored significantly better on the TVIP than on the PPVT, suggesting that their Spanish vocabulary was better than their English vocabulary. However, their performance on both the TVIP and PPVT fell below the average range, according to age-based norms. Participants performed significantly better in English than in Spanish on the majority of the symbolic number tasks, including Counting Out Loud, Counting Objects, Give-N, and Numeral Identification. Children's Spanish versus English performance did not differ significantly on the Scaffolded Number Line task (likely due to very low average performance). These results are in contrast to Iglesias (2012) who found no significant differences between

participants' Spanish and English performance on any of their measures of early math skills. It is possible that factors such as different geographical location (i.e., the aforementioned study was conducted in Florida) may be responsible for these divergent results. Nonetheless, for our participants, performance tended to be better in English, the language of instruction. This implies that preschool plays an important role in the development of their numerical knowledge. Furthermore, it suggests that these children are receiving more number-relevant input from their teachers than from their parents. Additionally, our findings suggest that these children do not need to be tested in Spanish and English in order to get a good first approximation of their math skills; testing could only be done in English, if time or resources are limited. However, testing in both languages provides a more holistic and accurate portrayal of their true capabilities.

To determine whether low-income Spanish-English bilinguals' early math skills were commensurate with their same-aged peers, we compared their performance to that of higher-income bilinguals, low-income monolinguals, and higher-income monolinguals. On the PPVT, monolinguals scored significantly better than bilinguals and higher-income children scored significantly better than low-income children, suggesting that bilinguals and low-income children were behind in their English receptive vocabulary. However, the effect of income did not differ for monolinguals and bilinguals. On all of the number tasks, low-income bilinguals performed similarly to low-income monolinguals; however, they performed significantly worse than higher-income bilinguals and monolinguals. Interestingly, bilinguals performed significantly better on the Counting Objects task than monolinguals. These findings suggest that income level, more so than language status, affects early math skills. Therefore, the low-income Spanish-English bilinguals in our study tend to be behind in their numerical knowledge because they are low-income, not because they are bilingual. Our results are in line with a study by Xue

et al. (2012) in which low-income bilingual preschoolers were also behind in early math, yet contrast with work by Iglesias (2012) whose participants performed comparably to same-aged peers. Xue and colleagues' research was conducted in southern California, as was ours; however, Iglesias's research was carried out in Florida. Thus, geographical location may be the reason why our findings are again not consistent with Iglesias, yet are with Xue et al.

Our finding that low-income children performed significantly worse than their higher-income counterparts on various numerical tasks is not surprising; the role of income on early math abilities is well documented in the literature (Ginsburg & Russell, 1981; Griffin, Case, & Siegler, 1994; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Jordan, Kaplan, Olah, & Locuniak, 2006; Jordan, Huttenlocher, & Levine, 1992; Jordan & Levine, 2009; Jordan, Levine, & Huttenlocher, 1994; Kirk, Hunt, & Volkmar, 1975; Saxe, Guberman, & Gearhart, 1987; Siegler, 2009; Starkey, Klein, & Wakeley, 2004). However, previous studies have found that income-related differences have an impact on symbolic number tasks but not on nonverbal number tasks. For instance, in a study by Jordan, Huttenlocher, & Levine (1992), while middle-income children did better than low-income children on math tasks involving verbal reasoning skills, middle- and low-income children did not perform differently on nonverbal math tasks. In our study, low-income children performed significantly worse on our nonsymbolic numerical discrimination task, suggesting that income may have an influence on some types of nonverbal numerical tasks.

One limitation of our study is that low- and higher-income bilinguals were not from the same ethnic backgrounds. This pattern reflects the demographic makeup of southern California; very few higher-income Hispanic/Latino Spanish-English bilinguals live in this area. However, there is little reason to believe that ethnicity, in and of itself, is related to the differences found between low- and higher-income bilinguals in the current study. Previous research has shown

that children from different ethnic backgrounds do not differ on math tasks when socioeconomic status is taken into account (Ginsburg & Russell, 1981).

Another limitation of the present study is the difficulty level of the math tasks. Ceiling performance was common, especially among higher-income children on some of the tasks, including Counting Out Loud and Counting Objects, suggesting that these tasks were too easy for many of the participants. Additionally, floor performance was common on the Scaffolded Number Line task, indicating that this task was too hard. Therefore, future studies may benefit from including a wider variety of number tasks so that there is more variation in the data.

A final, related limitation is that we did not utilize a standardized measure of mathematics achievement. Therefore, it is somewhat difficult to compare our results to the few other studies on this particular topic (i.e., Iglesias, 2012; Xue et al., 2012), since both of those studies used the WJ III ACH. However, we were not satisfied with the way certain tasks were administered on the standardized math tests available for preschoolers. Therefore, we chose to create our own battery instead, with similar tasks that are commonly found on those tests but with a slightly different way of asking the questions of interest. Future researchers who wish to use their own battery of tasks may find it useful to include a standardized math assessment as well, in order to make comparisons across studies easier.

In conclusion, we found that low-income Spanish-English bilinguals were behind on all of the numerical tasks, compared to their higher-income peers; their performance was similar to that of low-income monolinguals. Additionally, they generally performed better in English than in Spanish. These findings represent an important addition to the limited research that exists on the early math skills of low-income Spanish-English bilingual preschoolers. More research is needed in this area to determine the generalizability of the current study, as well as what other

potential factors, besides income, may be playing a role in their math development. This in turn can inform efforts to create suitable interventions to boost the math skills of these children to put them on a path toward success in their academic careers.

SUMMARY AND CONCLUSIONS

The studies in the preceding chapters were designed to expand upon the limited research available on numerical cognition in bilingual preschoolers. In Chapter 1, we investigated whether bilingual children are better than monolinguals at ignoring perceptually misleading information. A longstanding question in the research literature is whether speaking more than one language helps a child perform better on certain types of cognitive tasks. One possibility is that bilingualism confers either specific or general cognitive advantages on tasks that require selective attention to one dimension over another (e.g., Bialystok, 2001; Hilchey & Klein, 2011). Other studies have looked for such an advantage but found none (e.g., Morton & Harper, 2007; Paap & Greenberg, 2013). This study compared monolingual and bilingual children's performance on a nonverbal numerical discrimination task, which required children to ignore area and attend to number. Children were asked which of two arrays of dots had "more dots." Half of the trials were congruent, where the numerically greater array was also larger in total area, and half were incongruent, where the numerically greater array was smaller in total area. All children performed better on congruent than on incongruent trials. Older children were more successful than younger children at ignoring area in favor of number. Bilingual children did not perform differently from monolingual children either in number discrimination itself (i.e., identifying which array had more dots) or at selectively attending to number. This study thus finds no evidence of a bilingual advantage on this task for children of this age.

In Chapter 2, we compared the consistency of bilingual preschoolers' knowledge of number words across their two languages to their knowledge of color words and common nouns. One prominent account of number-concept development (Carey, 2009) predicts that bilingual preschoolers' number-word knowledge should be more closely correlated across their two

languages than their knowledge of other kinds of words. This is because learning the meaning of a word in one language's count list should make it easy to infer the meaning of the corresponding word in another language's count list. Thus, when a bilingual child eventually constructs the concept of "three," it may also be applied to the third word in any other count list she knows. This is not predicted for other kinds of words because word learning in those domains does not rely on a placeholder structure like counting. Mandarin-English and Spanish-English bilinguals were asked to give a specific number of items, a specific color, or a specific animal or vehicle (for common nouns) to a stuffed animal to assess their knowledge of these different word types. Children were tested once in each language. We found that knowledge of number words was more consistent across languages than knowledge of color words and common nouns for Spanish-English bilinguals, but not for Mandarin-English bilinguals; thus, Carey's proposal was only partially supported.

In Chapter 3, we explored the numerical knowledge of low-income Spanish-English bilingual preschoolers, a population that has been greatly understudied. Previous research has shown that the numerical knowledge that children acquire before kindergarten is the single best predictor of later academic achievement (e.g., Duncan et al., 2007). Yet, low-income children enter kindergarten far behind their higher-income peers (e.g., Jordan, Huttenlocher, & Levine, 1992). While a number of researchers have examined the numerical knowledge of monolingual preschoolers, few have done so with bilingual preschoolers. This study consisted of two parts: an examination of whether low-income Spanish-English bilinguals' performance depended on the language of testing, and a comparison of low-income Spanish-English bilinguals to higher-income bilinguals, low-income monolinguals, and higher-income monolinguals. Participants were administered a vocabulary measure and a battery of numerical tasks. We found that

participants performed significantly better in English than in Spanish on the majority of the tasks, although performance was strongly correlated across languages on the Give-N task. Furthermore, low-income bilinguals performed similarly to low-income monolinguals on all of the number tasks, verbal and nonverbal alike; however, they performed significantly worse than higher-income bilinguals and monolinguals. Our results suggest that the low-income Spanish-English bilinguals in our study tend to be behind in their numerical knowledge because they are low-income, not because they are bilingual.

Although these three studies clearly represent distinct contributions to the field, we can make some general conclusions. Findings from Chapters 1 and 3 suggest that bilingualism does not seem to affect certain areas of nonverbal numerical cognition, specifically nonsymbolic numerical discrimination. Furthermore, results from Chapters 2 and 3 suggest that bilingualism does seem to have an influence on particular components of symbolic numerical cognition, namely number-word learning; thus, underscoring the importance of language in number-concept development. Additionally, findings from Chapter 3 indicate that income does seem to have an effect on both nonverbal and symbolic numerical cognition. Collectively, these studies provide insight into how learning more than one language may or may not impact various aspects of numerical cognition in preschool-aged children.

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