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Explaining Individual Differences in Trajectories of Simultaneous Bilingual Development: Contributions of Child and Environmental Factors

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Effects of child and environmental factors in moderating the course of bilingual development were investigated using longitudinal data, from age 2.5 to 5 years, on 126 U.S.-born children with early exposure to Spanish and English. Multilevel models of Spanish and English expressive vocabulary identified children's phonological memory ability as a significant predictor of both outcomes, while also replicating the effect of the relative amount of language exposure. In addition, nonverbal IQ was a significant predictor of English vocabulary; birth order and maternal education in Spanish were significant predictors of Spanish vocabulary. These findings expand our understanding of the sources of the wide heterogeneity in bilingual development and of the requirements that language acquisition makes of learners and their environments.

Dual language exposure from birth is both a common human experience and a potentially informative circumstance in which to investigate the requirements that language acquisition makes of both the learner and the learner's environment. For example, studies of bilingual development have revealed, even more clearly than studies of monolingual development, that language growth depends on the amount and quality of language exposure the environment provides (Hoff, 2018; Unsworth, 2016). Studies of simultaneous bilingual development have paid less attention to the requirements made of the learner, even though the literature on monolingual development finds evidence that individual differences in language growth arise from individual differences in language learning ability, as well as from differences in experience.

Another gap in current studies of early bilingualism is a dearth of longitudinal studies of development during the preschool years. There is a growing literature on bilingual infants (e.g., Byers-Heinlein, Morin-Lessard, & Lew-Williams, 2017; Werker, 2018) and a large literature on school-aged bilingual children (e.g., August, McCardle, & Shanahan, 2014; Rojas & Iglesias, 2013), whereas fewer studies have described bilingual development between 2 and 5 years. Previous reports in the literature, some of which made use of subsamples of the same database as this study, have begun to describe early bilingual development and have identified some properties of the environment that account for individual differences during this developmental period (Hoff, Burridge, Ribot, & Giguere, 2018; Hoff & Ribot, 2017; Place & Hoff, 2016). The aim of this study was to add child characteristics to this emerging account.

Two theoretical frameworks are particularly relevant to the enterprise of building an explanation of bilingual development. One is Bronfenbrenner's bioecological model of human development (Bronfebrenner & Morris, 1998), which provides a useful framework for identifying and organizing factors that are likely to play a role. In this model, development occurs as a result of interactions between the developing person and social partners, within a nested set of contexts, and influenced by historical time. Thus, the model points to characteristics of the person (i.e., the child), and characteristics of the child's environment at different distances from the child as influential factors. The processes that occur where the child meets the environment are the

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engines of development. This model has been elaborated and applied to multilingual development by Bornstein (2013), who identified gender, among other person characteristics, and exposure and family education level, among context features, as factors with likely effects on the acquisition of more than one language. A second relevant theoretical framework is that of usage-based theories of language acquisition, according to which language acquisition is the result of the learner's cognitive processes applied to the incoming speech stream while also drawing information from the communicative setting in which the speech occurs (Christiansen & Chater, 2016; Tomasello, 2015). Thus, this theoretical framework points to children's cognitive skills and properties of the speech the children hear as influential factors. The starting point for this study is the solid evidence that for children who are exposed to two languages, environmental factors, notably the quantity and quality of language exposure, have been demonstrated to moderate that outcome. Here we add child factors to models of language growth in bilingually developing children.

Child Characteristics That Influence Language Development

Multiple social and cognitive abilities support language acquisition. The human ability to mutually engage with others about objects and events and the ability to learn patterns have been proposed as foundational skills upon which language acquisition depends (Tomasello, 2015). Indeed, individual differences in the onset of joint attention (Brooks & Meltzoff, 2008) and in the ability to learn patterns (aka statistical learning; Kidd & Arciuli, 2016) have been found to predict language development. Other cognitive abilities with relations to language growth include speed of lexical retrieval (DeAnda, Hendrickson, Zesiger, Poulin-Dubois, & Friend, 2018; Weisleder & Fernald, 2013) and nonverbal intelligence (Collins, O'Connor, Suárez-Orozco, Nieto-Castañon, & Toppelberg, 2014; Farnia & Geva, 2011).

A particular focus of this study is the ability to remember new sound sequences. Not only is the ability to remember incoming speech logically prerequisite to analyzing that speech for semantic and structural regularities, but this ability, termed phonological memory, shows clear and early individual differences (Hoff, Core, & Bridges, 2008), with wide ranging effects on language development (Gathercole, 2006). Phonological memory skills have been found to be related to the development of vocabulary and grammar in monolingual first language acquisition (Gathercole, 2006; Hoff et al., 2008), to success at foreign language learning in the classroom (Service, 1992), to second language learning among immigrant children and children from immigrant families (Farnia & Geva, 2011; Paradis, 2011; Verhagen, Leseman, & Messer, 2015), and to performance in a laboratory word learning task (Adlof & Patten, 2017). Poor phonological memory skills are a hallmark of children with a developmental language disorder (Bishop, North, & Donlan, 1996; Marton & Schwartz, 2003).

Phonological memory is typically assessed using nonword repetition tasks, in which children are asked to repeat meaningless sequences of sounds. Nonword repetition taps several domains related to phonological processing, including auditory perception and analysis, the representation of phonological information, the capacity to store and recall phonological information, and articulation skill (Gathercole, 2006). Phonological memory appears to have both an unlearned and learned component. The unlearned component operates over all speech-like stimuli without drawing on information in long term memory. It is inborn and heritable (Bishop, 2002; Kovas et al., 2005). The learned component makes use of knowledge in long-term memory that has been acquired through language experience (Vallar, 2006). Evidence of this learned component includes findings that children show better memory for high-frequency sound sequences in nonwords than for low-frequency ones (Edwards, Beckman, & Munson, 2004; Munson, Kurtz, & Windsor, 2005), and they show better memory for sound sequences that conform to the phonology of their own language than for sound sequences drawn from a foreign language (Thorn & Gathercole, 1999). Children who are native speakers of a language show a greater effect of the frequency sound sequences (i.e., phonotactic probability) than children who are second language speakers and, presumably, have had less experience with the language (Messer, Leseman, Boom, & Mayo, 2010).

Bilingual children's nonword repetition performance is better for stimuli that share phonological properties of the language they have heard more compared to their performance for stimuli like words in the language they have heard less (Gutiérrez-Clellen & Simon-Cereijido, 2010; Parra, Hoff, & Core, 2011; Summers, Bohman, Gillam, Peña, & Bedore, 2010). When bilingual children's development in two languages is predicted, nonword repetition accuracy is a better predictor when the nonwords conform to the phonological constraints of the predicted language (Masoura & Gathercole, 1999; Parra et al., 2011). The contribution of phonological memory skills to explaining individual differences in trajectories of dual language growth across the preschool period among simultaneous bilinguals has not been studied.

Gender is another characteristic of the child frequently found to be related to language development (Fenson et al., 1994; Galsworthy, Dionne, Dale, & Plomin, 2000). The source of this female advantage is not clear; it may include both biological and environmental components (Bornstein, Hahn, & Haynes, 2004). Some previous studies of Spanish-English bilingual samples in the United States have found an advantage to older girls in Spanish acquisition, but not English acquisition (Duursma et al., 2007; Rojas & Iglesias, 2013), which they interpreted as reflecting daughters' stronger familial ties compared to sons, rather to any biological factor.

Finally, we consider birth order as a property of the child, not because it denotes any characteristics inherent in the child, but because, all other factors being equal, children with different birth orders have been found to have different language outcomes. In monolingual families, first borns tend to be more advanced in vocabulary and grammatical development, whereas later borns are more precocious in their communicative skill (Hoff, 2006). In immigrant families, first-born preschool children show stronger skills in their families' heritage language than do later born children at the same age (Bridges & Hoff, 2014).

Environmental Characteristics That Influence Language Development

Among environmental characteristics, the quantity and quality of children's language experience are robust predictors of children's language development. Evidence of effects of the quantity of language exposure in studies of English and Spanish monolingual children consists of many findings that children who are talked to more develop language at a faster rate than children who are talked to less (Hoff, 2006; Weisleder & Fernald, 2013). Evidence of quantity of exposure effects in studies of simultaneous bilingual children consists of multiple findings that children exposed to two languages acquire them at different rates, as a function of how much they hear each language (Hoff, 2018; Unsworth, 2016).

Evidence of the effects of the quality of exposure on language growth has appeared in studies of monolingual development as correlations between differences among mothers in the informative properties of the speech they address to their children and differences among their children in their rates of language development (Hoff, 2003; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). In studies of bilingual development, the evidence of effects of exposure quality is consistent with the findings from studies of monolingual children, but it is less direct: the proportion of language exposure provided by native speakers (Paradis, 2011; Place & Hoff, 2011, 2016) and the proficiency of the nonnative sources of exposure (Jia, Aaronson, & Wu, 2002; Paradis & Jia, 2017) are both positive predictors of development in the majority language among first and second generation immigrant children, and native speaker status and proficiency among nonnative speakers is related to the informative properties of child-directed speech (Hoff, Core, & Shanks, 2019).

Studies of monolingual parents and children suggest that parents' level of education is an indicator of the quality of children's language-learning environments. Maternal education is related to properties of child-directed speech that support language development (Hoff, 2003, 2006; Rowe, 2008). Previous analyses of a subsample of participants in the current study found, among children acquiring two languages, relations between maternal education and child language development that were specific to the language in which mothers attained that level of education (Hoff et al., 2018). Such language specificity is consistent with the notion that properties of mothers' speech mediate effects of maternal education on child language development. Although the number of studies of effects of paternal education is fewer, there is also evidence that fathers influence their children's language acquisition and that paternal education levels affect the behavior that mediates that influence (Cabrera & Bradley, 2012; Pancsofar, Vernon-Feagans, & The Family Life Project Investigators, 2010).

The Present Study

The aim of this study was to investigate the influence of internal characteristics of children and characteristics of their environments on the development of English and Spanish in U.S.-born children from Spanish-speaking homes. The measured characteristics of the children were their phonological memory skills, their nonverbal intelligence, their gender, and their birth order. The measured characteristics of the children's environments were the relative amount of their home language exposure that was in English and in Spanish and their mothers' and fathers' levels of educational achievement in English and in Spanish.

Children's language development was measured using their scores on a standardized test of expressive vocabulary in English and Spanish. We focused on this measure of language skill for three reasons: (a) It is an important outcome. Children's vocabulary knowledge at school entry is a significant predictor of their subsequent success in learning to read (e.g., Kieffer, 2012; Lee, 2011); (b) A large literature links phonological memory skills with vocabulary development (e.g., Gathercole, 2006); and (c) It is possible to achieve measurement equivalence on this variable across this age range.

The children in this study are participants in an ongoing longitudinal study of language development in children from Spanish-speaking homes. The selection of the measures of children's language learning environments was informed by prior findings from subsamples of current sample (Hoff et al., 2018; Hoff & Ribot, 2017). The investigation of the influence of characteristics of the child on growth, the prediction of vocabulary size at age 5, and the use of the full sample in this longitudinal study to test the combined influence of child and environmental characteristics are new.

Method

Participants

The participants were 126 children (61 girls, 65 boys) from Spanish-speaking families in the United States whose home environments and English and Spanish skill were assessed at 6-month intervals between the ages of 2.5 and 5 years. All children met the criteria that at least one parent was born in a Spanish-speaking country and that Spanish was spoken in the home, either exclusively or in combination with English. All children were born in the United States, were full term and healthy at birth, and had normal hearing based on parent report of otoacoustic emissions tests performed in the hospital. All children were screened for evidence for communicative delay at 2.5 years using the Ages and Stages Questionnaire (Squires, Potter, & Bricker, 1999). Participants were recruited through advertisements in local magazines, programs for parents with young children, and through word of mouth. Relative amount of English exposure at home ranged from 0% to 90% when the children began the study at age 2.5 years. (Mean levels of English exposure at each assessment point are presented in Table 3 in the results section.) Data were collected between 2010 and 2015 in South Florida. Participants' demographic characteristics are presented in Table 1.

Procedure

At the initial visit, primary caregivers provided informed consent for their and their children's participation, and they were administered an extensive interview including questions about language use in the home. Interviews were conducted either in the

Table 1
Participant Characteristics

	Percentage of sample (N = 126)
Child ethnicity	
European American	2.4
Hispanic White	93.7
Hispanic Black	2.4
African American	0.0
Other[a]	1.6
Mothers' highest level of education (in any language)	
College degree or higher	53.2
Fathers' highest level of education (in any language)	
College degree or higher	45.20
Mothers' native countries	
Columbia	30.2
Peru	13.5
United States	11.9
Venezuela	9.5
Cuba	7.1
Argentina	4.8
Puerto Rico	3.2
Mexico	3.2
Dominican Republic	2.4
Spain	2.4
Other	11.8
Fathers' native countries	
United States	25.4
Columbia	15.9
Peru	11.1
Venezuela	9.5
Cuba	9.5
Argentina	6.5
Mexico	4.8
Dominican Republic	4.8
Puerto Rico	2.4
Other	10.1
Single parent households (all mother only)	
At child age 2.5 years	7.1
At child age 5 years	11.9

[a]Other Spanish-speaking countries include Chile, Ecuador, El Salvador, Guatemala, Nicaragua, Panama, and Uruguay.

participants' homes, or a laboratory playroom, depending on the caregiver's preference. Approximately 85% of the interviews occurred in participants' homes. Following the caregiver interview, the children's English and Spanish skills were assessed in two separate sessions. The order of the English and Spanish assessments was counterbalanced across participants. Interviews to update home language use and other information and assessments of children's English and Spanish skill were repeated at 6-month intervals to child age 5 years.

Language Outcomes

Children's *English* and *Spanish expressive vocabularies* were assessed using the Expressive One Word Picture Vocabulary Test, Bilingual Edition (EOWPVT; Brownell, 2001). The internal consistency of the test, calculated at each age level, ranges from $\alpha = .92$ to $\alpha = .97$, depending on age, and the test–retest correlation is .91, according to the test manual (Brownell, 2001). The standard administration procedure for the Spanish-English bilingual version is to allow the child to provide a label in either language. We modified this procedure to allow only English labels in the English assessment, and only Spanish labels in the Spanish assessment in order to obtain separate estimates of the children's English and Spanish vocabularies, as have others (Anthony et al., 2009). Because this is not the standard administration procedure, the test does not have norms for children's English or Spanish scores. Thus, we use raw scores in all analyses. Scores observed in this sample range from zero (the lowest score obtained by a child at 2.5 years) to 76 (the highest, winsorized score obtained in English by a 5-year-old).

Child Characteristics

Gender

Gender was assigned based on primary caregiver report and coded as 0 = female, 1 = male.

Child Birth Order

Birth order was also reported by the primary caregiver and coded dichotomously as 0 = first born or only child and 1 = later born.

Child Age

Age was entered into statistical analyses as the target assessment age. Assessments were conducted within 4 weeks of the target ages of 2.5, 3, 3.5, 4, 4.5, and 5 years. Children's exact ages at the first day of testing at each assessment point were calculated for purposes of the sample description in Table 3.

Phonological Memory

Phonological memory skill was measured as the accuracy with which children repeated Spanish-like and English-like nonwords (i.e., nonwords that conformed to Spanish and English phonotactics, respectively). For each language, the stimuli included four 2-syllable, four 3-syllable, and four 4-syllable nonwords. The nonwords were created from real words in the MacArthur–Bates Communicative Development Inventory (Fenson et al., 1993) for 16- to 30-month-olds and its Spanish version, the Inventario del Desarrollo de las Habilidades Comunicativas (Jackson-Maldonado et al., 2003). The nonwords phonologically matched real words by syllable length so that they contained the same consonant and vowel sounds as the real words and used the same phonotactic frames and stress patterns as the words they were derived from. For example, the English words *balloon* and *chicken* became the nonwords *challoon* and *bicken*, and the Spanish words *muñeca* and *gallina* became the nonwords *gañeca* and *mullina*. This ensured that nonwords were phonologically similar to words children typically acquire at 2.5 years in each language. The complete list of nonword stimuli with the real words on which they were based is provided in Supporting Information.

The tasks using English- and Spanish-like stimuli were administered by native speakers of each language, on separate days in counterbalanced order. Examiners were trained to present items in a standard protocol based on toy naming. After a brief warm-up period, the examiner showed the child a small toy animal or person-like figure and said, for example, "Look, this is *Challoon*. Can you say *Challoon*?" Examiners presented items no more than three times before moving on to the next item. This test was administered with a real word repetition test, not reported here. All children in the present sample attempted to repeat at least three items in each language in either the real or nonword repetition test, which was the criterion for calculating repetition accuracy. Data on this measure were missing for three children for the English stimuli and six children for the Spanish stimuli because of equipment failure.

Repetition accuracy was measured as the percent of consonants correctly repeated (PCC), based on broad transcription of each repetition attempt in the International Phonetic Alphabet and consensus scoring. Final transcriptions and calculation of PCC were achieved in the following manner: Each session was audio- and video-recorded and those recordings were entered into Phon, a software program for the transcription, annotation and analysis of phonological and phonetic data (https://www.phon.ca; Rose & MacWhinney, 2014). Using Phon's double-blind transcription tool, two graduate-level research assistants, who were trained in English and Spanish phonetics, independently transcribed each repetition attempt. A third trained research assistant acted as validator. When the two independent transcriptions agreed, the validator accepted the transcription as the final transcription. In 17% of attempted items, two transcribers did not agree and final transcription was determined by the validator, the second author, or the validator in consultation with the second author. One percent of repetition attempts were excluded from the data because background noise or overlapping speech prevented accurate transcription. Once transcriptions were completed, we used the PCC function available within Phon 2.2 (https://www.phon.ca; Rose & MacWhinney, 2014) to calculate PCC for each set of stimuli, obtaining separate scores for English and Spanish.

This method of broad transcription and consensus scoring is widely regarded as the best approach to achieving maximum transcription reliability (Pye, Wilcox, & Siren, 1988; Shriberg, Kwiatkowski, & Hoffmann, 1984). Our rate of initial agreement between independent transcribers (83%) is similar to prevalidation values reported elsewhere using this consensus method with child speech (Morris, 2009), and it is higher than agreement levels previously reported for independent transcribers of child speech data (Louko & Edwards, 2001; Stoel-Gammon, 2001).

Nonverbal IQ

Nonverbal IQ was measured only at age 5 years using the Primary Test of Nonverbal Intelligence (PTONI; Ehrler & McGhee, 2008). Instructions were given in whichever language the child appeared to prefer, and the test itself is entirely nonverbal. Each item consists of five different images, and the child's task is to identify the single image that does not have the attribute shared by the others. Early items are images of real objects; later items are abstract designs. Children must successfully complete five practice trials before the test begins to ensure that they understand the task. Standard scores were calculated based on published norms, with a mean of 100 (*SD* = 15). The norms are based on a culturally and ethnically diverse sample of 1,010 children residing in 38 U.S. states.

Environment Characteristics

Relative Quantity of Exposure

The relative amount of the target child's language exposure in the home that was in English (*English exposure)* and in Spanish (*Spanish exposure*) were estimated by primary caregivers in response to the question, *What percent of the time are English and Spanish spoken to (target child) in the home*, which was asked in the context of an extensive interview about the target child's language experience. The measures of English and Spanish exposure are reciprocal, with the exception of measures for one child whose parents reported using a third language at home 5% of the time. Caregiver estimates of the relative amount of language exposure have been widely used in studies of bilingual development and have been found to be reliable when compared to measures obtained from day-long recordings (Byers-Heinlein et al., 2019) and to have high validity against the criteria of expressive and receptive vocabulary (DeAnda, Bosch, Poulin-Dubois, Zesiger, & Friend, 2016; Hoff et al., 2012). Reliability in this study was calculated by correlating the estimates caregivers provided in interview at child age 2.5 with data on the target child's exposure to English and Spanish recorded in 7-day diaries that the mothers' kept (Place & Hoff, 2016). Diary data were available for 108 of the 126 children in this study. The correlation between caregivers' estimates of the relative amount of English exposure at home and the diary-based measure of percent of time exposed to "English only" or to "mixed, mostly English" input at home was $r = .637$, $p < .001$; the corresponding numbers for Spanish were $r = .606$, $p < .001$.

Maternal and Paternal Educational Attainment

Maternal and paternal education in English and *Maternal and paternal education in Spanish* were measured using mothers' reports of the highest level of education each parent completed in each language. We coded education using three categories, with 0 = no education at all in that language, 1 = less than a college degree, and 2 = a college degree or higher. We take this approach rather than using a continuous measure of years of education because such a measure would have neither interval scale properties nor a normal distribution in this sample (see Table 2).

Statistical Analysis Plan

The distributions of all continuous variables were examined for deviations from normality. Scores on the outcome measures were winsorized to reduce effects of extreme outliers by converting values that were 3 *SD*s above the mean to the value of the highest score within 3 *SD*s of the mean. In the sole case where there were two outliers on the same measure (i.e., Spanish vocabulary at 30 months) the higher outlier was converted to the value of the highest score within 3 *SD*s, plus 1 (Salkind, 2010). After winsorizing the outcome scores, all measures of predictors and outcomes had skewness and kurtosis values with less than an absolute value of 1, with the exception of Spanish vocabulary scores at the youngest age, which had a high proportion of 0 scores.

To examine the predictors and outcomes for multicollinearity, we calculated the correlations among the interval level predictors, the associations among the dichotomous predictors, the mean differences in the interval level predictors associated with the dichotomous predictors, and the correlations between the outcomes at each time point.

Table 2
Descriptive Statistics for Time-Invariant Predictors

Predictors	*n*	
Gender		
% female	126	48.4
Birth order		
% first born	126	40.5
Mothers' education in English		
% with any schooling		50.0
% college degree or higher		43.7
Mothers' education in Spanish	126	
% with any schooling		79.4
% college degree or higher		41.3
Fathers' education in English		
% with any schooling		59.5
% college degree or higher		46.0
Fathers' education in Spanish	126	
% with any schooling		67.5
% college degree or higher		28.6
English phonological memory (at 2.5 years)		
M (*SD*) percent consonants correct	123	45.03 (26.10)
Spanish phonological memory (at 2.5 years)		
M (*SD*) percent consonants correct	120	44.43 (26.73)
Nonverbal IQ (at 5 years)		
M (*SD*) standard score	124	113.07 (15.19)

As a first step in data analysis, we calculated the zero-order associations between the hypothesized predictors and the English and Spanish vocabulary outcomes at the time points that anchor the longitudinal data—child ages 2.5 and 5 years. The purpose of calculating these correlations was to exclude from the modeling those candidate predictors with no significant relation to the outcome at either 2.5 or 5 years.

We then calculated a series of longitudinal multilevel models with English and Spanish vocabulary scores as the outcomes. For each outcome, we first calculated an unconditional growth model including children's age (with six time points) as a fixed and random effect, and centered at 30 months. For both English and Spanish vocabulary, these models confirmed nonzero slopes and intercepts. Additionally, the random error terms associated with the intercept and slope were significant, indicating that heterogeneity may be explained by Level 2 (between-individual) predictors (intercept: $p < .001$; slope: $p = .002$).

Next, we calculated a base model (Model 1) that included child age (Age) and the relative amount of language exposure (Exposure) because both have clear, previously established relations to child vocabulary. Subsequently, in Model 2, we entered all predictors, the quadratic effect of age (Age^2), and all two-way interactions with Age and Age^2. Model 2 thus tested each predictor's effect on the mean level of the outcome between 2.5 and 5 years, on the linear slope of growth during that period, and on the quadratic component of the growth curve—if there is a significant quadratic component. The final model, Model 3, was achieved by trimming nonsignificant interaction terms from Model 2. In these models, all predictors are entered as time-invariant covariates, that is, characteristics assumed to be constant over the period of development studied—with the exception of the relative amount of English and Spanish exposure. The continuous predictors, relative proportion of home language exposure, phonological memory score, and nonverbal IQ were mean centered.

Three fit statistics were used: the change in −2 log-likelihood (−2LL), the Akaike information criterion, and the Bayesian information criterion. Comparisons of fit between models were accomplished using chi-square difference tests using the −2LL (−2LL model fit index) from each model. The final growth models of English and Spanish vocabulary, including significant predictors and interactions, had significantly better model fit than the base models. Random effects for all models included intercept and linear slope. Missing data were assessed using Little's MCAR test and were found to be missing completely at random ($\chi^2(3) = 3.82$, $p = .15$). Missing data were handled using full information maximum likelihood. The models were computed via maximum likelihood estimation and unstructured covariance structures. All models were run in SPSS Statistics, Version 24.0, software (IBM Corp, 2016). Power analysis based on previously observed effect sizes (Place & Hoff, 2016) demonstrate that a sample size of 43 would yield a power of .80 to detect a medium effect size, compared to a constant group effect, and sample size of 120 would allow detection of differences in slope. Thus, the current sample size of 126 should allow detection of moderate or moderate to large effects (Hedeker & Barlas, 1999; Hedeker, Gibbons, & Waternaux, 1999).

Results

Descriptive Statistics for Predictor and Outcome Measures

Descriptive statistics for the predictor variables that were measured once (time-invariant predictors) are presented in Table 2. All time-invariant characteristics were measured at the initial assessment (age 2.5 years) except nonverbal IQ, which was assessed at 5 years. Descriptive statistics for the predictor variables that were measured at each assessment point (time-varying predictors) and for the language outcomes at each assessment point are presented in Table 3.

Interrelations Among Predictors and Among Outcomes

The intercorrelations within the predictor and outcome variables are presented in the Supporting Information. The measures of home language use at each assessment point were highly correlated, but there were mean level differences over time (see Table 3) and thus they were entered as time-varying covariates. In no case were the correlations among other predictors too high to examine independent effects.

Preliminary Analyses

The zero-order associations between all candidate predictors and the English and Spanish vocabulary outcome measures at the first and final assessment points (i.e., ages 2.5 and 5 years) are presented in Table 4. Based on these findings, we excluded birth order from the model of English vocabulary growth, and we excluded gender, nonverbal IQ, and paternal education from the model of Spanish vocabulary growth. The zero-order correlations also led to our using phonological memory assessed with English-

Table 3
Descriptive Statistics for Time-Varying Predictors and Outcome Measures at Each Assessment Point

	Assessment point (child age in years)					
	2.5	3	3.5	4	4.5	5
Child age in months						
M (*SD*)	30.40 (0.39)	36.45 (0.38)	42.42 (0.39)	48.41 (0.37)	54.46 (0.41)	60.50 (0.56)
n	126	75	96	110	107	126
English home input (%)						
M (*SD*)	33.71 (25.45)	34.17 (27.43)	34.12 (25.62)	37.05 (26.97)	38.83 (26.36)	41.86 (27.02)
n	126	75	96	110	107	126
Spanish home input (%)						
M (*SD*)	66.28 (25.70)	65.65 (27.42)	65.77 (25.70)	62.89 (26.94)	61.17 (26.36)	58.10 (27.04)
n	126	75	96	110	107	126
English EOWPVT raw score						
M (*SD*)	8.26 (9.55)	17.04 (13.82)	26.35 (15.69)	33.39 (15.26)	43.13 (13.32)	50.33 (12.11)
n	126	70	89	107	115	126
Spanish EOWPVT raw score						
M (*SD*)	5.96 (8.25)	11.16 (10.93)	14.46 (13.82)	15.19 (13.90)	17.74 (15.66)	19.38 (16.46)
n	126	75	94	110	117	126

Note. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.

Table 4
Zero-Order Associations Between Candidate Predictors and English and Spanish Vocabulary Scores at 2.5 and 5 Years

	Outcome measures			
	2.5 years old		5 years old	
Predictors	English vocabulary	Spanish vocabulary	English vocabulary	Spanish vocabulary
Gender[a]	**−0.232****	0.012	−0.039	−0.036
Birth order[a]	−0.091	−0.158	−0.118	**−0.218***
English phonological memory[a]	**0.476*****	**0.227***	**0.419*****	0.143
Spanish phonological memory[a]	**0.312*****	**0.409*****	**0.202***	**0.351*****
Nonverbal IQ[a]	**0.215***	0.021	**0.421*****	0.027
Relative English input at home[a]	**0.526*****	**−0.346****	**0.397*****	**−0.512*****
Mother's education in English[b]	**6.45****	na	**6.25****	na
Mother's education in Spanish[b]	na	**4.36***	na	**6.01****
Father's education in English[b]	**4.34***	na	**6.34****	na
Father's education in Spanish[b]	na	< 1	na	< 1

Note. Significant correlations in boldface.
[a]Test of association is Pearson *r*. [b]Test of association is $F(2, 125)$ based on a one-way analysis of variance with three categories of education: No schooling in that language, schooling achieving less than a college degree, schooling achieving a college degree or more.
$*p < .05$. $**p < .01$. $***p < .001$.

like stimuli to model of English vocabulary growth and phonological memory assessed with Spanish-like stimuli to model of Spanish vocabulary, because the within-language correlations between phonological memory and vocabulary were stronger that the across-language correlations.

Predictors of English Vocabulary

Table 5 presents the models of English vocabulary with the model fit indicators. Model 1 confirmed the expected effect of relative amount of English exposure on children's English expressive vocabulary. Model 2 indicated an additional significant positive effect of phonological memory skill assessed in English and a significant Age × Nonverbal IQ interaction. In the final model, the significant and positive predictors of English expressive vocabulary were relative Exposure to English and Phonological Memory for English-like sound sequences. The Age × Nonverbal IQ interaction term was also significant, indicating that Nonverbal IQ was a significant, positive predictor of the rate of English vocabulary growth. These effects are plotted in the left-hand panels of Figures 1–3.

Predictors of Spanish Vocabulary

Table 6 presents the models of Spanish vocabulary growth with the model fit indicators. Model 1 confirmed the expected significant effect of relative amount of Exposure to Spanish on children's Spanish expressive vocabulary. Model 2 indicated an additional significant negative effect of Birth Order (first-born children had higher Spanish vocabulary scores than later-born children), a significant positive effect of Phonological Memory for Spanish-like sound sequences, a significant positive effect of Mother having a College Degree in Spanish, a significant Age × Birth Order interaction indicating that first-born children grew in Spanish vocabulary at a faster rate than later-born children, and a Age × Maternal Education in Spanish indicating that mothers having had any school experience in Spanish was associated with their children growing in Spanish at a faster rate than when mothers never attended school in Spanish. In the final model (Model 3), the significant predictors of mean levels of Spanish vocabulary were Exposure, Birth Order, Phonological Memory, and Mothers having a College Degree earned in a Spanish language institution. The significant, positive predictors of the linear rate of growth were Birth Order, with first borns growing faster, Mothers having some Education in Spanish. In addition, there was a significant negative quadratic component in the growth function (Age^2), indicating that the rate of growth in Spanish vocabulary decelerated over time. These effects are plotted in the right-hand panels of Figures 1, 2, 4, and 5.

Effect Size Estimates

To provide estimates of the size of the effects of the significant predictors, we used the parameter

Table 5
Predicting English Expressive Vocabulary, as Measured by the EOWPVT, Between 2.5 and 5 Years, Estimates of Fixed Effects (and SEs) From a Series of Growth Models (N = 126)

	Model 1	Model 2	Model 3	Model 3 p value
Intercept	4.68 (1.12)***	7.78 (1.78)***	6.74 (1.65)	< .001
Age	8.26 (0.18)***	7.58 (1.14)***	8.59 (0.54)	< .001
English exposure	0.12 (0.02)***	0.10 (0.03)***	0.10 (0.02)	< .001
Gender		−1.74 (1.73)	−1.18 (1.57)	.454
Phonological memory in English		0.14 (0.04)***	0.15 (0.03)	< .001
Nonverbal IQ		0.04 (0.06)	0.08 (0.05)	.146
Mother educated in English		−0.40 (3.45)	−0.21 (3.11)	.946
Mother college degree in English		3.56 (3.50)	3.75 (3.16)	.238
Father educated in English		3.74 (2.76)	4.72 (2.47)	.058
Father college degree in English		−4.11 (2.61)	−4.15 (2.36)	.082
Age^2		0.06 (0.22)	−0.07 (0.10)	.704
Age × English Exposure		0.02 (0.02)		
Age × Gender		0.09 (1.12)		
Age × Phonological Memory in English		0.02 (0.02)		
Age × Nonverbal IQ		0.10 (0.04)**	0.04 (0.01)	< .001
Age × Mother Educated in English		0.58 (2.18)		
Age × Mother College Degree in English		0.27 (2.21)		
Age × Father Educated in English		1.83 (1.88)		
Age × Father College Degree in English		−1.08 (1.77)		
Age^2 × English Exposure		−0.01 (0.00)		
Age^2 × Gender		0.10 (0.21)		
Age^2 × Phonological Memory in English		0.00 (0.00)		
Age^2 × Nonverbal IQ		−0.01 (0.01)		
Age^2 × Mother Educated in English		−0.14 (0.42)		
Age^2 × Mother College Degree in English		−0.05 (0.42)		
Age^2 × Father Educated in English		−0.40 (0.36)		
Age^2 × Father College Degree in English		0.35 (0.34)		
Goodness of fit				
−2LL	4,434.630	4,175.093	4,202.032	
AIC	4,448.630	4,237.096	4,234. 032	
BIC	4,479.649	4,373.294	4,304.329	

Note. Model 1 includes Age and Exposure as predictors. Model 2 adds Gender, Phonological Memory in English, Maternal Education in English, Paternal Education in English, Age^2, and all two-way interactions with Age and Age^2. In Model 3, all nonsignificant interaction terms are trimmed; this is the most parsimonious model. −2LL = −2 log-likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.
**$p < .01$. ***$p < .001$.

estimates in the final models to calculate the size of the lag in vocabulary development, in months, between the children with lower and higher scores on each predictor, holding other parameters constant. To illustrate, the predicted English vocabulary score at 5 years (60 months) for children with phonological memory scores in the 25th percentile is 47.66. The same model predicts that the children in the 75th percentile for phonological memory ability will achieve that score at 55.80 months, indicating that the children in the 25th percentile are 4.20 months behind children in the 75th percentile in expressive vocabulary development at the age of 4 years, 8 months. For all significant predictors we report lags calculated based on the vocabulary score achieved by the lower performing children at 3 years and at 5 years.

Effect Sizes for Predictors of English Vocabulary Scores

The lags between the children at the 25th percentile and the 75th percentile in phonological memory ability, calculated at 3 and 5 years, were 4.05 and 4.20 months, respectively. The lag attributable to the difference between 30% exposure to English and 70% exposure to English at home was 2.90 months at 3 years and 3.01 months at 5 years. The size of the lags attributable to phonological

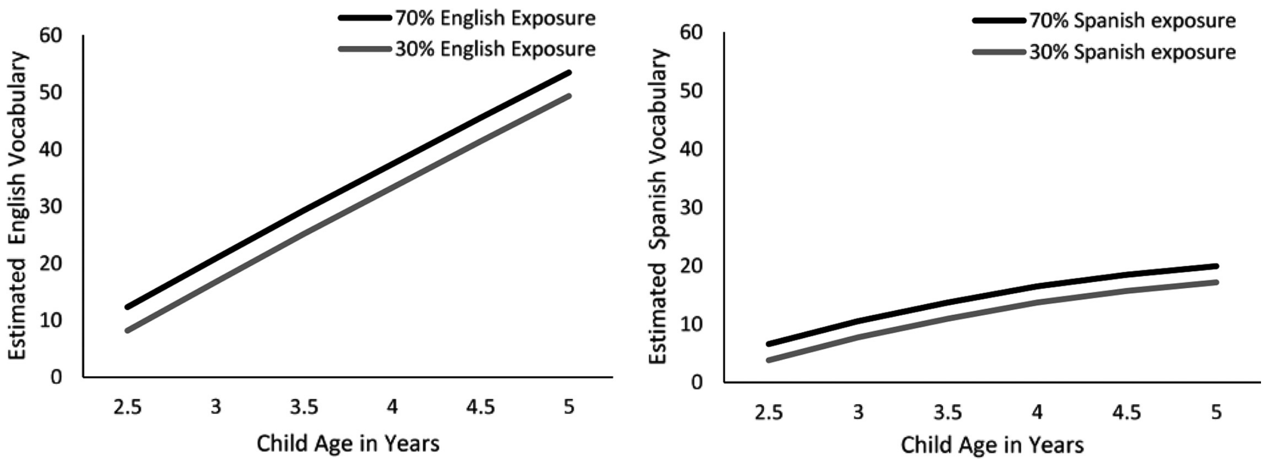

Figure 1. Predicted trajectories of English vocabulary growth (left panel) and Spanish vocabulary growth (right panel; EOWPVT scores) from 2.5 to 5 years based on the final models (Tables 5 and 6) and plotted for values of the relative amount of home language exposure that is in the outcome language at 30% and 70%. All other predictors in the final model were set at the mean value for the sample. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.

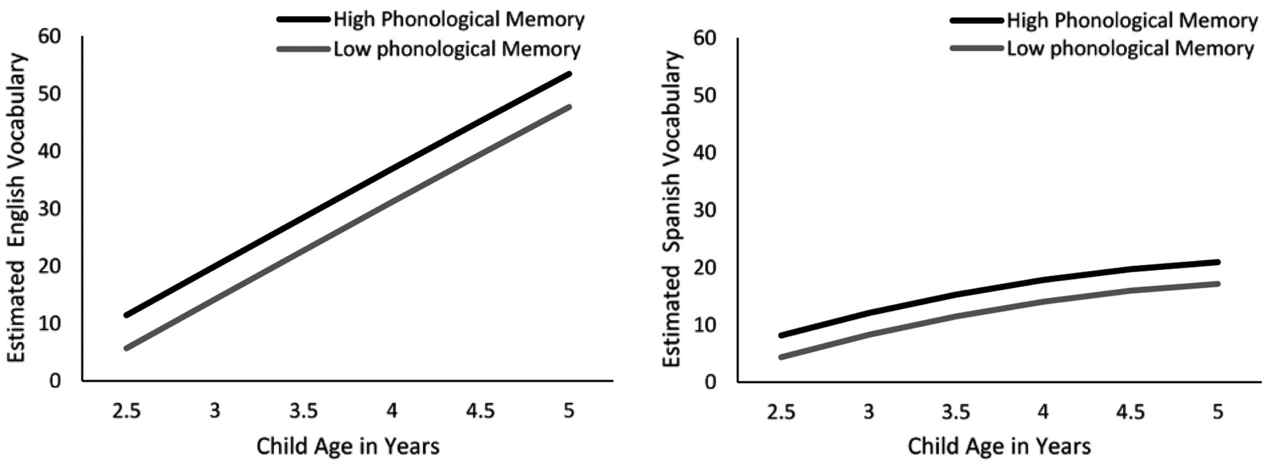

Figure 2. Predicted trajectories of English vocabulary growth (left panel) and Spanish vocabulary growth (right panel; EOWPVT scores) from 2.5 to 5 years based on the final models (Tables 5 and 6) and plotted for values of phonological memory at the 25th and 75th percentile for the sample, with phonological memory assessed for stimuli conforming to phonological properties of the outcome language. All other predictors in the final model were set at the mean value for the sample. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.

memory and relative exposure at home are almost constant throughout this developmental period because these factors did not affect the slope of growth and because growth in English vocabulary was essentially linear between 2.5 and 5 years. In contrast, the size of the estimated lag in English vocabulary growth attributable to nonverbal IQ increased over time because nonverbal IQ was associated with differences in the rate of growth. At 3 years, the children at the 25th percentile within this sample in terms of nonverbal IQs had the same estimated English vocabulary scores as did the children at the 75th percentile 1.42 months earlier. At 5 years, that lag was 3.40 months. (It is worth noting that because these predictors were correlated, the lags associated with the predictors are not perfectly additive.)

Effect Sizes for Predictors of Spanish Vocabulary Scores

Because the rate of growth in Spanish vocabulary decelerated over time, the size of lags associated with each predictor were greater at 5 years than at 3 years. That is, when growth is slower, it takes more time for children who lag to catch up. The lags between the children at the 25th percentile and

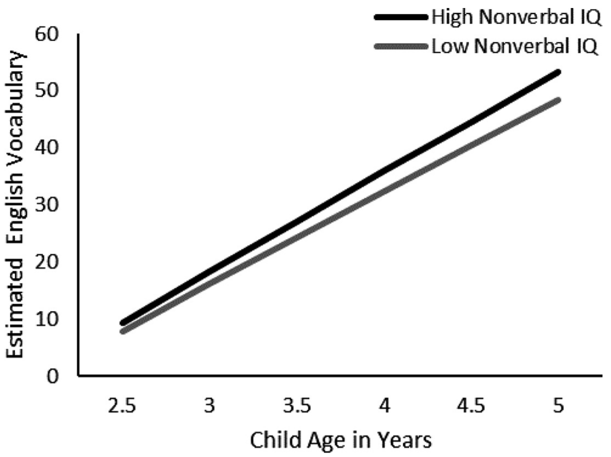

Figure 3. Predicted trajectories of English vocabulary growth (EOWPVT scores) from 2.5 to 5 years based on the final model (Table 5) and plotted for values of nonverbal IQ (PTONI scores) at the 25th and 75th percentile for the sample. All other predictors in the final model were set at the mean value for the sample. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition; PTONI = Primary Test of Nonverbal Intelligence.

the 75th percentile in phonological memory ability calculated at 3 and 5 years were 5.84 and 13.74 months, respectively. The lag attributable to the difference between 30% exposure to Spanish and 70% exposure to Spanish at home was 4.39 months at 3 years and 11.05 months at 5 years.

The lag between first borns (including only children) and later borns was 5.66 months at 3 years and 19.45 months at 5 years. The difference in children's Spanish vocabularies associated with whether or not the mother had any schooling in Spanish was 5.65 months at 3 years and 23.04 months at 5 years. The mothers with no schooling were not uneducated; they were either not immigrants from a Spanish-speaking country, in which case the father was, or in 8 cases the mother immigrated as a young child prior to attending school. The additional lag in children's Spanish vocabulary growth associated with whether the mother had a college degree earned in Spanish was 4.27 months at 3 years and 10.02 months at 5 years.

Discussion

The aim of this study was to investigate the contribution of child and environmental characteristics to explaining individual differences in early bilingual development. We modeled growth in English and Spanish expressive vocabularies from 2.5 to 5 years for 126 children who were born in the United States and raised in Spanish-speaking homes, with at least one parent who was an immigrant from a Spanish-speaking country. The child characteristics considered, in addition to age, were gender, birth order, phonological memory ability, and nonverbal IQ. The environmental characteristics considered were the relative amount of exposure to each language, and maternal and paternal educational in Spanish-speaking institutions (attained prior to immigration for immigrant parents) and in English-speaking institutions (attained after immigration for those parents who were immigrants).

Findings in the Zero-Order Associations Between Predictors and Outcomes

Zero-order associations between predictors and outcomes at the two time points that anchor these longitudinal data were calculated so that hypothesized predictors with no evidence of relations to the outcome could be excluded from the modeling process. In addition to the identification of significant predictors, which appear in the models, there are other findings in these correlations that are not apparent in the final models, but are worth noting.

The zero-order correlations showed that the relation between phonological memory skills and vocabulary is stronger when the stimuli to be remembered in the phonological memory task share the phonological properties of the language in which vocabulary size is measured. That is, a child's ability to remember Spanish-like sound sequences is more useful to the acquisition of Spanish than is the ability to remember English-like sound sequences, and *vice versa*. Thus, phonological memory is not only an inborn language-general learning skill (Bishop, 2002), but it also becomes a target language-specific language (or languages) learning skill, as other findings have also suggested (Parra et al., 2011).

In the zero-order associations, significant differences in children's English vocabulary were associated with their mothers' and fathers' educational attainment in English, but in the full models those relations were not significant, suggesting other variables in the model share variance with both parental education and children's outcomes. Just how parents' education is related to these other variables and how those variables might carry the effect of education on language development are topics for future research. (In contrast, differences in children's Spanish vocabulary were associated with their mothers', but not fathers', level of education

Table 6

Predicting Spanish Expressive Vocabulary, as Measured by the EOWPVT, Between 2.5 and 5 Years, Estimates of Fixed Effects (and SEs) From a Series of Growth Models (N = 126)

	Model 1	Model 2	Model 3	Model 3 p value
Intercept	1.80 (1.28)***	5.07 (1.75)**	4.97 (1.66)	.003
Age	2.70 (0.21)***	3.14 (1.04)**	3.73 (0.61)	< .001
Spanish exposure	0.08 (0.02)***	0.04 (0.02)*	0.07 (0.02)	< .001
Birth order		−2.85 (1.44)*	−3.19 (1.36)	.021
Phonological memory in Spanish		0.12 (0.03)***	0.10 (0.02)	< .001
Mother educated in Spanish		1.83 (1.99)	2.51 (1.86)	.177
Mother college degree in Spanish		3.54 (1.56)*	2.90 (1.45)	.048
Age^2		−0.18 (0.19)	−0.31 (0.07)	< .001
Age × Spanish Exposure		0.02 (0.02)		
Age × Birth Order		−1.70 (0.85)*	−1.04 (0.41)	.013
Age × Phonological Memory in Spanish		0.00 (0.02)		
Age × Mother Educated in Spanish		3.01 (1.20)*	1.39 (0.51)	.007
Age × Mother College Degree in Spanish		−0.70 (0.91)		
Age^2 × Spanish Exposure		0.00 (0.00)		
Age^2 × Birth Order		0.17 (0.15)		
Age^2 × Phonological Memory in Spanish		0.00 (0.00)		
Age^2 × Mother Educated in Spanish		−0.39 (0.22)		
Age^2 × Mother College Degree in Spanish		0.15 (0.16)		
Goodness of fit				
−2LL	4,271.289	3,948.127	3,962.651	
AIC	4,285.289	3,992.127	3,990.651	
BIC	4,316.464	4,088.896	4,051.232	

Note. Model 1 includes Age and Exposure as predictors. Model 2 adds Birth Order, Phonological Memory in Spanish, Maternal Education in Spanish, Age^2, and all two-way interactions with Age and Age^2. In Model 3 all nonsignificant interaction terms are trimmed; this is the most parsimonious model. −2LL = −2 log-likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.
*$p < .05$. **$p < .01$. ***$p < .001$.

in Spanish in both the zero-order associations and the final model.)

Findings in the Models of English and Spanish Expressive Vocabulary Growth

Three variables emerged as significant predictors of bilingual children's expressive vocabulary in both of the languages they were acquiring: age, relative amount of exposure to each language, and phonological memory skill. One variable predicted only English: nonverbal IQ. Two variables predicted only Spanish: child birth order and maternal education in the outcome language. In the next sections, we interpret these findings in the context of the extant literature on bilingual development.

Child Effects

Child Age Effects

As would be expected, children's vocabularies in both languages grew over time. There was a significant linear component to the growth function for both languages. Growth in Spanish also had a significant negative quadratic component, indicating the growth slowed during this period. In monolingual children, over this age range, vocabulary growth typically decelerates (Huttenlocher et al., 2010). Thus, the present finding of only a linear function for English is most straightforwardly interpreted as evidence that bilingual children, who, on average, have smaller single-language vocabularies for their age than monolingual children (Hoff et al., 2012), decelerate later than monolingual children.

This proposal is consistent with other findings from studies of bilingual children that the children with smaller initial English vocabularies grow faster in English skills than children with larger initial vocabularies once they enter school (Rojas & Iglesias, 2013). The decelerating growth curve for Spanish requires a different explanation because the children's Spanish vocabularies were smaller than their English vocabularies. Whatever the reason for the deceleration of Spanish growth, these results indicate that with equivalent levels of English and

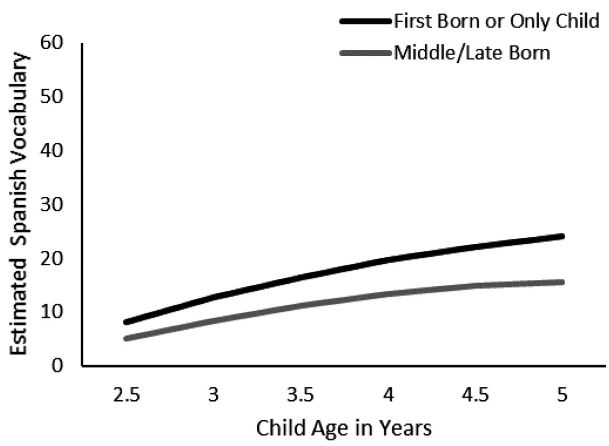

Figure 4. Predicted trajectories of Spanish vocabulary growth (EOWPVT scores) from 2.5 to 5 years based on the final model (Table 6) and plotted for first born (including only) children and later born children. All other predictors in the final model were set at the mean value for the sample. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.

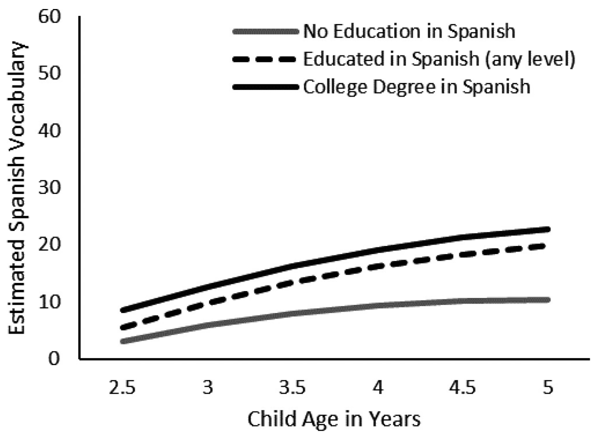

Figure 5. Predicted trajectories of Spanish vocabulary growth (EOWPVT scores) from 2.5 to 5 years based on the final model (Table 6) and plotted for children with a mother with no schooling Spanish, schooling in Spanish less than a college degree, and schooling including earning a college degree in Spanish. All other predictors in the final model were set at the mean value for the sample. EOWPVT = Expressive One Word Picture Vocabulary Test, Bilingual Edition.

Spanish exposure at home, children from Spanish-English bilingual homes in the United States will become increasingly English dominant over time in expressive language skills. This conclusion is consistent with other findings in the literature on the difficulty of maintaining heritage language skills (Montrul, 2012) and with evidence from young adults raised in Spanish-speaking homes in the United States. that even those who are bilingual as adults have weaker Spanish than English skills (Giguere & Hoff, 2020).

Gender Effects

Gender was not a significant predictor in the model of English vocabulary growth, although gender did show a modest zero-order correlation with English vocabulary at 2.5 years, with girls showing higher scores than boys. Gender was not significantly related to Spanish vocabulary in the zero-order correlations and thus not pursued further.

These findings are consistent with previous findings that gender effects on language development are small and more likely to be observed in children under 3 years (Fenson et al., 1994; Galsworthy et al., 2000). In the previous literature, early gender differences in language development have been attributed to the earlier maturation of girls, to girls' spending more time in activities that involve talk, and to girls' spending more time with adults, among other factors (Bornstein et al., 2004). The present data suggest phonological memory as another factor that contributes to the female advantage in early language development. Girls had significantly higher phonological memory scores than boys for assessments using both Spanish- and English-like sound sequences (see correlations in Supporting Information). The present findings differ from findings in the literature that among children of Spanish-speaking immigrants, girls acquire stronger Spanish skills than boys (Duursma et al., 2007; Rojas & Iglesias, 2013). We found no evidence of such a gender effect in this study.

Phonological Memory Effects

Phonological memory ability, measured as repetition accuracy for nonwords that conform to the phonology of the outcome language and assessed at 2.5 years, was a significant predictor of children's English and Spanish vocabulary over the period from 2.5 to 5 years. Phonological memory had only main effects; it did not predict growth. Thus, if we think of phonological memory skill as an invariant characteristic of children that predicts the rate of language development, the present findings suggest that it operates early—before the age of 2.5 years.

This interpretation is consistent with other findings of effects of phonological memory on language growth between the ages of 22 and 25 months (Parra et al., 2011), but it is inconsistent with the finding that phonological memory skill predicts vocabulary growth between 4 and 5 years

(Gathercole, Willis, Emslie, & Baddeley, 1992). In that same study, Gathercole et al. (1992) found that phonological memory did not predict vocabulary growth at older ages, rather vocabulary size predicted phonological memory. Together these findings are consistent with the argument that the relation between phonological memory and vocabulary is bidirectional. Phonological memory skills support vocabulary growth, and, as children's vocabularies grow, their phonological representations become more fine-grained, a process referred to as lexical restructuring (Edwards et al., 2004; Metsala, 1999). More fine-grained representations, in turn, facilitate children's performance on phonological tasks such as phoneme nonword repetition (Verhagen, Boom, Mulder, & Leseman, 2019). The present findings from bilingual children add to that account evidence that while the inborn component of phonological memory skill is language neutral, the skill becomes more specific to the language or languages in which vocabulary is being acquired, perhaps as a result of shaping by growing vocabularies.

Nonverbal IQ Effects

Nonverbal intelligence, assessed only at 5 years, was a significant predictor of the rate of English vocabulary growth. Nonverbal IQ was not entered into the model predicting Spanish because the zero-order correlations with Spanish vocabulary assessed at 2.5 and at 5 years were near zero.

One reason that nonverbal IQ predicted English, but not Spanish language development may be the different circumstances of children's exposure to English and Spanish. Spanish is learned at home more than English is, and nonverbal intelligence may be more relevant to learning from out-of-home and less supportive environments than to learning in the arguably more supportive home environment. Hakuta (1987) suggested a similar explanation of the correlation found between English skill and a measure of nonverbal intelligence in a sample of children from Spanish-speaking homes in New York City. Another potential explanation is that vocabulary knowledge is used in this ostensibly nonlinguistic task because words serve as verbal mediators that aid in representing the nonlinguistic relation that needs to be held in mind during stimulus search. Children's English vocabularies might play a greater role in this task than their Spanish vocabularies if children's English vocabularies are more sophisticated than their Spanish vocabularies, as was the case for this sample, which was English-dominant at the time the test was administered. These explanations are entirely speculation. However, there are at least two other findings that nonverbal intelligence is related to majority language skills, but not minority language skills in bilingual children (Blom, 2019; Hakuta, 1987), suggesting the relation may be real. If so, this finding raises interesting questions for future research regarding differences among social contexts in the cognitive demands they make of children with respect to language learning.

Birth Order Effects

Birth order was a significant predictor of Spanish, but not English vocabulary. First-born and only children had larger Spanish vocabularies than later-born children. Other research on heritage language development has also found that that first-born children in immigrant families have stronger heritage language skills than later born children (Bridges & Hoff, 2014) and are more likely in adulthood to have maintained that language (Yamamoto, 2001). There was no evidence in the present data of a general first born advantage, as other studies have found (Hoff, 2006), but it is not surprising that the many variables that influence bilingual development would swamp the typically small general effect of birth order.

Environmental Effects

Language Exposure Effects

The relative amount of home exposure to each language had significant effects on English and Spanish vocabulary, as expected, and as many previous studies have documented (Hoff, 2018; Unsworth, 2016). The effects were only main effects. During the period from 2.5 to 5 years, growth rates did not differ as a function of exposure suggesting either a unique effect of exposure that occurs early —before 2.5 years—or that home exposure is more relevant early and its unique effects are attenuated by increasing levels of exposure outside the home as children get older.

Parent education effects

Neither mothers' nor fathers' education was a significant predictor of children's English vocabulary in the final model, and only maternal education was significant predictor of children's Spanish vocabulary. Because both mothers' and fathers' education in English was a significant source of variance in children's English vocabulary at 2.5 and 5 years when considered in isolation from the other variables, the most reasonable interpretation of that final model is that the multiple other sources of variance correlated with parents' English educational attainment accounted for the effect of parental education. Fathers' education in Spanish was unrelated to children's Spanish vocabulary in the zero-order correlations, but mothers' education achieved in Spanish was a significant predictor of children's Spanish vocabulary—evidenced in two significant effects in the final model. One, mothers having attained a college degree in Spanish (prior to immigration) was associated with mean differences in their children's Spanish vocabulary; and two, mothers having any schooling in Spanish—as opposed to having immigrated with no schooling or being the U.S.-born parent in the household—was associated with faster rates of Spanish vocabulary development during the period of the study.

The first findings repeat the previously reported effect of maternal education, which has been interpreted as reflecting the effect of higher quality language exposure provided by more educated speakers (Hoff et al., 2018). The effect of any schooling in Spanish on the slope of Spanish growth is more straightforwardly interpreted as an effect on Spanish vocabulary development of having a mother who is either a native English speaker and thus the father being the source of native Spanish in the household or having a mother who immigrated at such a young age that she herself is a heritage Spanish speaker.

Limitations

This study is of children exposed to two languages in a context where the languages are not equal in status nor equivalent in the circumstances of use. The outcomes and the factors that influence those outcomes may be different in environments where both languages have equal status in outside the home (Smithson, Paradis, & Nicoladis, 2014). An important task for future research is to document the effects of different contexts of dual language exposure on the course of bilingual development and to explain how the distal factors in the social contexts exert those effects.

This study is also limited by the measures employed. The measures of the language learning environment were caregiver estimates of proportional exposure to each language, not direct measures of the absolute amount of exposure, and of parents' education, not direct measures of the properties of the language exposure they provided their children. In interpreting the present findings, it is important to keep in mind that whereas measures of relative exposure involve a necessary tradeoff between how much a child hears each language, the absolute amount of exposure to two languages can vary independently. The outcome measures in this study were a single measure of skill in each language, one standardized test of expressive vocabulary. Because we investigated predictors of each language separately, we do not account for the total language knowledge these bilingual children possess. The current search for predictors of individual differences should also be addressed with respect to bilingual children's linguistic knowledge combined across languages and with respect to domains other than expressive vocabulary. Last, there are other variables, unexamined in this study, that likely affect bilingual development including, for example, typological distance between the two languages and parent and child attitudes toward each language (Bornstein, 2013). These, too, are factors to be addressed in future research.

Summary and Conclusions

Worldwide, many children experience a social context like that of the participants in this study—one in which they hear a language at home that is not the majority language of the country in which they live. For these children, achieving proficiency in the majority language is necessary for academic and occupational achievement, and achieving proficiency in their heritage language is valuable for the development of ethnic identity and for positive family relationships (Oh & Fuligni, 2010). In order to support the majority and heritage language development of children in this social context, it is necessary to identify malleable factors that are positive predictors of the acquisition of each language.

While the findings of this study implicated two child characteristics, phonological memory ability and nonverbal intelligence, as sources of individual differences in bilingual development, the findings also implicated children's exposure and parents' level of education in each language as contributing environmental factors. Because the effects of the environmental factors are substantial and because the child factors are themselves shaped by experience, the present findings argue that there is room for enriched experience to optimize bilingual development.

Furthermore, the present findings make the point that supporting the acquisition of one language need not be at the expense of the other. The only significant predictor in the present findings that suggests the two languages compete in acquisition is the relative amount of exposure to each language. Although we did not measure it in this study, absolute amount of exposure is a better predictor of language growth (Marchman, Martínez, Hurtado, Grüter, & Fernald, 2017), and it involves no necessary tradeoff. Children's phonological memory skills were positive predictors of both English and Spanish vocabularies, and by the age of 2.5 years the children had acquired phonological memory skills tuned to each of the languages they were acquiring. Children's nonverbal IQ was a positive predictor of English vocabulary growth without being a negative predictor of Spanish vocabulary. Maternal education in English was a positive predictor of children's English vocabulary, with no negative effect on children's Spanish vocabulary, and *vice versa*. In sum, the present findings paint an optimistic picture of what is possible in bilingual development. The limiting factors are largely in the environment, not the child.

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