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The graded effects of bilingualism and language ability on children's cross-situational word learning

Kimberly Crespo[1] and Margarita Kaushanskaya[2]

[1]Boston University, Boston, MA, USA and [2]University of Wisconsin-Madison, Madison, WI, USA

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Corresponding author:
Kimberly Crespo;
E-mail: kcrespo@bu.edu

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Abstract

The present study examined whether length of bilingual experience and language ability contributed to cross-situational word learning (XSWL) in Spanish-English bilingual school-aged children. We contrasted performance in a high variability condition, where children were exposed to multiple speakers and exemplars simultaneously, to performance in a condition where children were exposed to no variability in either speakers or exemplars. Results revealed graded effects of bilingualism and language ability on XSWL under conditions of increased variability. Specifically, bilingualism bolstered learning when variability was present in the input but not when variability was absent in the input. Similarly, robust language abilities supported learning in the high variability condition. In contrast, children with weaker language skills learned more word-object associations in the no variability condition than in the high variability condition. Together, the results suggest that variation in the learner and variation in the input interact and modulate mechanisms of lexical learning in children.

1. Introduction

Cross-situational word learning (XSWL) – the ability to learn word-referent mappings by aggregating co-occurring statistics between words and referents over time (Smith & Yu, 2008; Yu & Smith, 2007) – is a fundamental mechanism underlying lexical acquisition. Individual differences in linguistic experiences, such as bilingualism, have not been fully explored in the context of XSWL. The handful of studies that have examined the effects of bilingualism on XSWL have focused on learning in adults (Benitez et al., 2016; Escudero et al., 2016; Poepsel & Weiss, 2016) and on group mean differences between bilinguals and monolinguals as the outcome measure for bilingualism effects. In the present study, we focused on XSWL in bilingual children and examined the graded effects of bilingual experience and language ability on XSWL performance. We were especially interested in whether different levels of bilingual experience and language ability would yield distinct consequences for XSWL under a condition of increased input variability.

1.1. Variability and XSWL

In everyday learning environments, children are exposed to productions from multiple speakers in the presence of multiple object exemplars. Yet, the effects of multiple speakers and object exemplars on learning have been historically investigated separately and across different disciplines, yielding a markedly mixed pattern of results. For example, in the speech processing literature, speaker variability is associated with poorer performance in children (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997). In contrast, in the explicit word learning literature, speaker variability has been shown to bolster young children's recognition and production of novel words and to support generalization to novel speakers (e.g., Apfelbaum & McMurray, 2011; Höhle et al., 2020; Quam et al., 2017; Richtsmeier et al., 2009; Rost & McMurray, 2010; but see Bulgarelli & Bergelson, 2023).

Similarly conflicting findings have been observed for manipulations related to exemplar variability, and facilitative effects of object exemplar variability on word learning and generalization have been reported (Ankowski et al., 2013; Gentner et al., 2007; Namy & Gentner, 2002; Nicholas et al., 2019; Perry et al., 2010; Twomey et al., 2014), but have not been consistently documented (e.g., Ankowski et al., 2013; Höhle et al., 2020; Maguire et al., 2008; Price & Sandhofer, 2021). For example, pediatric language intervention research suggests benefits of teaching new words via multiple object exemplars (Aguilar et al., 2018; Alt et al., 2014; Nicholas et al., 2019; Plante Oglivie, Vance et al., 2014). However, other empirical studies report no differences in learning when children are exposed to one object exemplar versus many (e.g., Höhle et al., 2020; Maguire et al., 2008). When studied jointly, null effects of combined speaker-exemplar variability are also observed (e.g., Nicholas et al., 2019). For example, Nicholas et al.

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(2019) reported that combining high variability in labels and objects was not effective in teaching prepositions to preschoolers. Taken together, the extant literature presents a perplexing picture, leaving open the question of whether variability in speakers and object exemplars influences children's lexical learning.

To date, only four studies have examined the effects of input variability on children's XSWL performance (Crespo & Kaushanskaya, 2021; Crespo et al., 2023; Crespo et al., 2024; McGregor et al., 2022). In general, the pattern of results suggests that children can successfully accommodate variability in a single dimension (i.e., multiple speakers *or* multiple exemplars). Conversely, variability in multiple dimensions (i.e., multiple speakers and exemplars) may interfere with children's statistical word learning performance, but such effects may be moderated by children's language experiences (Crespo et al., 2023). In a recent study, Crespo et al. (2023) found that bilingual children were significantly more likely to learn word–object pairs than monolingual children when variability was present in the input. Results also revealed that combined speaker-exemplar variability significantly hindered XSWL performance in monolingual children but not in bilingual children.

However, the study by Crespo et al. (2023) left many questions unanswered, and the categorical approach taken to index bilingualism limited our ability to pinpoint specific learner characteristics that influenced CSWL under conditions of increased variability. We were especially eager to examine this question *within* a group of bilingual children, because doing so would enable us to consider influences of both diversity in language experience and language ability on learning *within* the same population. Therefore, in the current study, we examined language experience and language ability as two separate continua in their influence on children's XSWL performance. This allowed us to test entirely distinct hypotheses via a novel analytical approach from Crespo et al. (2023) and pursue a more nuanced examination of interactions among the input, the learner, and XSWL performance.

The current investigation also extends beyond the scope of Crespo et al. (2023) by comparing learning in a combined variability versus no variability manipulation. In Crespo et al., 2023, we did not test this comparison and instead focused on how manipulations of variability within a single dimension (only exemplars or only speakers) influenced XSWL performance in comparison to when variability across both dimensions was manipulated. Given emerging evidence suggesting that bilingualism modifies XSWL performance under conditions of increased complexity (e.g., Benitez et al., 2016; Crespo et al., 2023; Escudero et al., 2016; Poepsel & Weiss, 2016), we believed that our bilingual dataset was ideally suited to an examination of how combined variability influenced XSWL in bilingual children with a range of language abilities.

1.2. Bilingualism and XSWL

There is a relatively small number of studies examining the effects of bilingualism on XSWL performance (Benitez et al., 2016; Crespo & Kaushanskaya, 2021; Crespo et al., 2023; Escudero et al., 2016; Poepsel & Weiss, 2016). The pattern of results generally suggests that bilingualism may not influence the development of core XSWL abilities, which is consistent with the broader statistical learning literature (Benitez et al., 2016; Crespo & Kaushanskaya, 2021; Poepsel & Weiss, 2016, but see Escudero et al., 2016). In general, when bilingual advantages are observed, they are specific to conditions that are congruent to bilingual experiences (Benitez et al., 2016; Poepsel & Weiss, 2016). For example, bilingual advantages in XSWL are observed when learners must map multiple words to one referent (Benitez et al., 2016; Poepsel & Weiss, 2016) and when novel words are increasingly complex (e.g., Benitez et al., 2016; Escudero et al., 2016). However, monolingual advantages have also been documented in XSWL performance, such that monolingual children were faster and more accurate at learning word-referent pairs than bilingual children (Crespo & Kaushanskaya, 2021).

It is unclear why bilingual XSWL advantages are observed in some studies (e.g., Escudero et al., 2016) but not others (e.g., Benitez et al., 2016; Crespo & Kaushanskaya, 2021).

While there may be multiple methodological reasons for the inconclusive pattern of results, some researchers have pointed out that the mixed findings may be rooted in methodological constraints associated with defining bilingualism as a categorical construct (e.g., Kaushanskaya & Prior, 2015). The related argument is that comparing bilinguals to monolinguals may limit our understanding of the mechanisms that explain changes to cognition and language as a function of bilingual experience (e.g., de Bruin, 2019; DeLuca et al., 2019; DeLuca et al., 2020; Kaushanskaya & Prior, 2015; Kremin & Byers-Heinlein, 2021; Marian & Hayakawa, 2021; Takahesu Tabori et al., 2018). Therefore, in the present study, we examined the effects of bilingualism on XSWL in a graded manner rather than categorically. We indexed bilingual experience as the length of time children had been exposed to both languages in their lifetime (see Luk, De Sa, & Bialystok, 2011; Meir & Armon-Lotem, 2013 for a similar approach).

Considering the full range of bilingual experiences has been shown to be a particularly useful approach to synthesizing the heavily contested findings on the effects of bilingualism on cognitive skills, such as executive functions (e.g., Adesope et al., 2010; Barac et al., 2016; Bialystok, 2011; Bialystok et al., 2009; Duñabeitia & Carreiras, 2015; Kapa & Colombo, 2013; Paap & Greenberg, 2013). Results from two recent studies suggest that bilingualism may have a graded effect on the development of cognitive skills (Sorge et al., 2017; Chung-Fat-Yim et al., 2020). For example, Sorge et al. (2017) found that higher levels of bilingualism in children (i.e., greater use of both languages in and outside of the home) were associated with better performance on a flanker task – a task that indexes attention and inhibition skills. In the current study, we posited a possibility of similar graded effects of bilingualism on XSWL, especially under conditions of increased input variability.

Exposure to both multiple speakers and exemplars may have negative consequences for XSWL given the increased inconsistencies in the signal: productions of words vary from speaker to speaker and perceptual properties vary across exemplars. Abstracting co-occurring statistics between labels and objects under conditions of increased variability may also require additional cognitive resources. Indeed, our earlier findings with monolingual children suggest that input variability may interfere with XSWL performance (Crespo et al., 2023, 2024). However, bilinguals may be able to adapt to increased variability, and our prior work indicates that as a group, bilingual children were less affected by combined variability than monolingual children on a XSWL task (Crespo et al., 2023). The mechanisms of such an effect are difficult to pinpoint, although there are some likely possibilities.

For instance, there is some evidence to suggest that bilingualism may boost the development of phonetic learning skills (e.g., Antoniou et al., 2015; Bialystok et al., 2003), word learning skills (e.g., Alt et al., 2019; Eviatar, Taha, Cohen, & Schwartz, 2018; Kaushanskaya, Gross, & Buac, 2014), executive functions (e.g., Bialystok & Martin, 2004; Carlson & Meltzoff, 2008; Kapa & Colombo, 2013; but see Duñabeitia et al., 2014; Paap et al., 2015; Nichols et al., 2020), and talker-voice processing abilities (Levi, 2018). Enhancements in these processes may make bilinguals particularly adept at accommodating fluctuations in speakers and exemplars during XSWL. The novel question asked in the current study was whether variability in bilingual experience *within* a bilingual sample would influence XSWL. The diverse language skills that characterized the sample also afforded a unique opportunity to explore the role of bilingual children's language ability in XSWL performance.

1.3. Language ability and XSWL

In addition to examining fluctuations in bilingual experience, we considered whether fluctuations in language ability would moderate the effects of variability on children's XSWL performance. Bilingual children have distributed lexical and morphosyntactic abilities across their two languages. Language ability in bilingual populations varies as a function of socioeconomic status, home language, and language use in the school setting, to name just a few relevant factors (e.g., Oller et al., 2007). Many typically developing bilingual children in the early stages of language acquisition experience temporary lags in acquiring language-specific skills, like vocabulary knowledge and grammatical tense (e.g., Bialystok, Luk, Peets, & Yang, 2010; Oller et al., 2007), resembling children with language impairment (e.g., Paradis, 2005; Paradis & Crago, 2000; Paradis et al., 2008). At the same time, bilingual children may display enhancements in other linguistic skills (e.g., word-learning abilities). Therefore, examining whether and how language ability contributes to XSWL performance is particularly interesting to explore in linguistically diverse learners.

Individual differences in monolingual's language ability have been linked to individual differences in XSWL performance (e.g., Hartley et al., 2020; McGregor et al., 2022; Scott & Fisher, 2012; Vlach & Debrock, 2017, 2019). In typically developing populations, children with robust language skills tend to learn more word-referent pairs in a XSWL task than children with weaker language skills (e.g., Scott & Fisher, 2012; Vlach & Debrock, 2017, 2019). In children with atypical language profiles, XSWL performance is poorer relative to typically developing children (e.g., Ahufinger et al., 2021; Broedelet et al., 2023; Hartley et al., 2020; McGregor et al., 2022, but see Venker, 2019). Therefore, we hypothesized that if XSWL is sensitive to weaknesses in bilingual children's language abilities within the normal range (i.e., in the absence of formal language impairment diagnoses), then children with weaker language skills will demonstrate poorer XSWL performance. However, if XSWL performance is not sensitive to variations in language ability within the normal range, then children will learn word-referent pairings similarly independent of language ability.

We were particularly interested in testing whether exposure to variable input would disproportionally impact XSWL performance in children with lower levels of language ability. Studies have shown that, like children with Developmental Language Disorder (DLD), children with sub-clinically weak language skills have subtle weaknesses in selective attention and display difficulties ignoring irrelevant cues during learning (e.g., Gandolfi & Viterbori, 2020; Marton, 2008; Pauls & Archibald, 2016). A recent study demonstrated that children with weaker language skills, but without a formal DLD diagnosis, displayed difficulties learning statistical regularities for artificial rules under increased learning demands (Crespo & Kaushanskaya, 2022). If accommodating input variability is taxing, then children with weaker language abilities would display poorer XSWL performance in the high variability condition than children with stronger language skills.

In the present study, we included children with poor-to-above-average language scores and operationally defined language ability as a continuum. A continuous approach to defining language ability is arguably a more robust analytical strategy than a categorical approach given the problematic over- and under-identification of language impairment in bilingual populations (e.g., Morgan et al., 2015; Samson & Lesaux, 2009). Examining bilingual children with a range of language skills allowed us to test whether bilingualism, language ability, or both influence XSWL performance under increased input variability.

1.4. The current study

In the present study, variability in a XSWL task was simultaneously manipulated along two dimensions – speakers and exemplars. We tested how fluctuations in bilingual experience and in language ability impacted children's ability to learn and generalize cross-situational statistics when variability was or was not present in the input. We compared children's performance in high variability, where children were exposed to multiple speakers and exemplars simultaneously, to performance in a condition where children were exposed to no variability in either speakers or exemplars. We took an exploratory approach to defining our hypothesis regarding the effect of variability, given the conflicting findings in the literature. On the one hand, input variability may interfere with children's XSWL performance, in line with speech perception literature (e.g., Creel & Jimenez, 2012; Lim et al., 2019; Ryalls & Pisoni, 1997) and models of speech processing that indicate increased cognitive effort associated with multiple-speaker input (Choi & Perrachione, 2019; Lim et al., 2019). On the other hand, we also considered the possibility that input variability might enhance XSWL in line with the explicit word and category learning literatures (e.g., Gentner et al., 2007; Namy & Gentner, 2002; Perry et al., 2010; Twomey et al., 2014).

A central question in the present study was whether children with different levels of bilingual experience and language ability would benefit from input variability to different degrees. It is challenging to make firm hypotheses about interactions between bilingualism and combined variability given the limited existing literature on the topic. Here we also considered two exploratory hypotheses. First, given that combined input variability negatively impacted XSWL performance in monolinguals but not bilinguals in our prior study (Crespo et al., 2023), we hypothesized that children with lower levels of bilingual experience may display weaknesses in learning from input variability to a greater degree than children with higher levels of bilingual experience. An alternative hypothesis is that children with low and high levels of bilingual experience may accommodate combined speaker-exemplar variability equally well.

We also anticipated that individual differences in bilingual children's language ability may be linked to variability in XSWL performance (e.g., Scott & Fisher, 2012; Vlach & Debrock, 2017, 2019). Specifically, we hypothesized that children with robust language skills would outperform children with weaker language skills (e.g., Scott & Fisher, 2012; Vlach & Debrock, 2017, 2019). We also hypothesized that the magnitude of the difference in performance between children with strong versus weak language skills would be greater under conditions of increased input variability. Our rationale stems from evidence suggesting that accommodating input variability during XSWL may be challenging (e.g., Crespo et al., 2023, 2024), and that children with weak language skills display weaknesses in XSWL (e.g., Ahufinger et al., 2021; Broedelet et al., 2023; McGregor et al., 2022) and in cognitive processes that may support learning under conditions of increased demands (e.g.,

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Gandolfi & Viterbori, 2020; Marton, 2008; Pauls & Archibald, 2016).

2. Methods

This study was reviewed and approved by the Education and Social/Behavioral Science Institutional Review Board at the University of Wisconsin-Madison. Children's legal guardians provided informed consent, and children provided oral assent. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. All data and scripts are openly available at https://doi.org/10.3886/E193325V1.

The sample of bilingual children in this study is the same as in Crespo et al. (2023). The current study included 37 typically developing Spanish–English bilingual participants (17 boys) aged 5–8 years. The lower limit of age 5 ensured that children could engage online via Zoom to complete our experimental tasks. The upper limit of age 8 ensured a range of bilingual experiences within our sample given the documented shift in language exposure and proficiency in Spanish to English during the early school years (e.g., Castilla-Earls et al., 2019; Anderson, 2012). Piloting revealed that children within this age range could reliably learn on the XSWL task without floor or ceiling effects.

Exclusionary criteria included a history of psychiatric or neurological disorders and a nonverbal IQ below 70 on the *Visual Matrices* subtest of the *Kaufman Brief Intelligence Test Second Edition* (KBIT-2, Kaufman & Kaufman, 2004). On average, children were first exposed to English and Spanish before their first birthday. Per parent report, children were exposed to English 59.27% and Spanish 40.73% of their waking hours. Mother's years of education were used as a proxy for SES and were collected through the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007). Information about children's language exposure in the home and language dominance was collected through a parent questionnaire. See Table 1 for participant characteristics.

Table 1. Participant characteristics, M (SD)

	Bilinguals	Range
N	37 (16 boys)	
Age	7.26 (1.09)	5.17–8.83
Mother's years of education	16.55 (3.53)	8–24
Nonverbal IQ[a]	114.00 (13.11)	72–133
First exposure to english (months)	12.05 (18.35)	0–54
Current english exposure (%)	59.27 (17.59)	15–90
English language skills[b]	101.91 (13.73)	75–122
First exposure to Spanish (months)	1.97 (08.17)	0–48
Current Spanish exposure (%)	40.73 (17.59)	10–85
Spanish language skills[c]	100.87 (13.32)	83–132
English vocabulary skills[d]	108.51 (17.19)	72–138
Spanish-english vocabulary skills[e]	134.61 (12.97)	97–145
Length of bilingual experience[f]	6.10 (2.23)	1.42–8.83
	n	
Race and ethnicity		
White and hispanic/latinx	25	
White and not hispanic/latinx	6	
Other and hispanic/latinx[g]	6	
Child's Dominant Language		
English	22	
Spanish	3	
English & Spanish equally	12	
Language Mostly Spoken at Home		
English	12	
Spanish	15	
English & Spanish equally	10	

[a]Visual Matrices subtest, *Kauffman Brief Intelligence Test – 2nd Edition*
[b]Standard Scores from Core Language Index Score from *Clinical Evaluation of Language Fundamentals – 5th Edition* (CELF-5)
[c]Standard Scores from Core Language Index Score from *Clinical Evaluation of Language Fundamentals – 4th Edition, Spanish* (CELF-4 Spanish)
[d]Standard Scores from *Expressive One-Word Picture Vocabulary Test – 4th Edition* (EOWPVT-4)
[e]Standard Scores from *Expressive One-Word Picture Vocabulary Test – 4th Edition, Spanish-Bilingual Edition* (EOWPVT-4 SBE)
[f]Child's current age - Age of second language acquisition
[g]Six caregivers reported *Other* but did not specify their race

2.1. Standardized measures

The *Clinical Evaluation of Language Fundamentals – Fifth Edition* (CELF-5; Wiig et al., 2013) was used to evaluate children's expressive and receptive language skills in English. The *Clinical Evaluation of Language Fundamentals – Forth Edition, Spanish* (CELF-4 Spanish; Wiig et al., 2006) was used to evaluate children's expressive and receptive language skills in Spanish.

We were interested in the robustness of the language system and did not want to penalize children for weaknesses in their language skills due to limited exposure. Therefore, in the current study, language ability was indexed by children's highest Core Language Index standard score from either CELF-5 or CELF-4 Spanish, in line with other studies examining language ability in bilingual children (Crespo et al., 2019; Crespo & Kaushanskaya, 2022; Peña et al., 2023). Recent work by Peña et al. (2023) demonstrates that when bilingual children's best score is considered, differences in language performance on standardized tests in English and Spanish are related to language ability and not language exposure in children with typical and disordered language skills.

Core Language Index standard scores are an omnibus measure of language ability, one that was designed to reflect receptive and expressive structural language skills. CELF-5 scores indexed language skills for 27 children; CELF-4 Spanish scores indexed language skills for 10 children. The highest Core Language Index standard score was below 1.25 SDs (standard scores ≤85) for three children. These participants were included in the analyses because there was no language disorder diagnosis nor parent concerns reported at the time of testing. Participants' highest CELF-4 Core Language Index standard scores ranged from 78 to 132.

The *Expressive One-Word Picture Vocabulary Test – Forth Edition* (EOWPVT-4; Martin & Brownell, 2011) and the *Expressive One-Word Picture Vocabulary Test – Forth Edition, Spanish-Bilingual Edition* (EOWPVT-4 SBE; Martin, 2013) were used to evaluate children's vocabulary skills. The EOWPVT assesses participants' ability to name objects, actions and concepts shown in

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colored illustrations. Participants were instructed to answer all test items in English on the EOWPVT-4 and in either Spanish or English on the EOWPVT-SBE.

Six children did not want to complete the EOWPVT-4 SBE. Inflated standard scores (i.e., standard scores 140–145) were observed for more than half of the children who completed the EOWPVT-4 SBE, creating a left-skewed distribution with little variability (i.e., a median of 140 and a mean of 134.61). Further inspection of the data revealed that these children answered all EOWPVT-4 SBE items in English and came from homes where parents reported some college education to doctoral degrees, education levels well above the average education levels reported in the norming sample. As a result, conceptual vocabulary scores from the EOWPVT-SBE did not appropriately quantify vocabulary skills in the current sample. Therefore, EOWPVT-4 SBE standard scores (M = 126.20, SD = 17.01; Range: 97–145) were used to index vocabulary skills for only 10 children who labeled items mostly, or all, in Spanish. EOWPVT-4 standard scores (M = 108.51, SD = 17.19; Range: 95–138) were used to index vocabulary skills for the remaining 26 children.

2.2. Length of bilingual experience

Length of bilingual experience was defined as the length of time children were exposed to English and Spanish concurrently. To calculate this variable, we subtracted the age of second language acquisition from children's current age. For example, if a 7-year-old child was exposed to Spanish at birth and English at 3 years, then their length of bilingual experience equaled 4 years.

2.3. Composite scores

See Table 2 for a correlation matrix. The multicon package (Sherman, 2015) was used to create unit-weighted composite scores for language ability and bilingual language experience. All variables were standardized (Z-scored) before creating the composites. We computed a language ability composite score ($\alpha_{\text{standardized}} = 0.76$; $r_{average} = 0.61$) that combined children's language skills scores (i.e., highest Core Language Index standard score from either the CELF-5 or CELF-4 Spanish) and vocabulary skills scores (i.e., EOWPVT-4 or EOWPVT-4 SBE standard score). Our goal in using a composite score was to capture the overall robustness of the linguistic system without penalizing children for weaknesses in English- or Spanish-specific skills.

We also computed a bilingual experience composite score ($\alpha_{\text{standardized}} = 0.88$; $r_{average} = 0.79$) that combined children's length of bilingual language experience and age of English acquisition. We reasoned that combining length of bilingual experience and English age of acquisition would render a more robust index of children's experience, one that would capture fluctuations in experience with both languages. Notably, the addition of English exposure ($\alpha_{\text{standardized}} = 0.68$; $r_{average} = 0.42$) reduced Cronbach's alpha below acceptable levels (i.e., 0.70; Nunnally & Bernstein, 1994) and was therefore not included in the bilingual composite score. The language ability and bilingual language experience composite scores did not significantly correlate ($r = 0.25$, $t(35) = 1.52$, $p = .14$).

2.4. Experimental task

Children completed a XSWL task in two experimental conditions in a within-subjects design.

All experiments were administered via Gorilla (https://gorilla.sc), an online platform for building and hosting experiments online. We focused our experiment on the learning of English-like novel words because in the school-aged range, children are typically exposed to more English than Spanish (e.g., Castilla-Earls et al., 2019; Anderson, 2012), and we aimed to maximize the

Table 2. Correlation matrix

	Age	Mom Yrs of Ed	English AOA	English expos	Spanish AOA	NV IQ	Lang ability	Vocab skills	Bi exp	NV[e]
Mother's years of Education	−0.34*									
English age of acquisition	−0.23	−0.39*								
English exposure	−0.08	0.12	−0.33*							
Spanish age of acquisition	−0.05	0.08	−0.16	0.19						
Nonverbal IQ[a]	−0.11	0.38*	−0.16	−0.07	−0.19					
Language ability[b]	−0.46**	0.64***	−0.40*	0.16	0.18	0.42**				
Vocabulary skills[c]	−0.14	0.32	−0.34*	−0.06	0.20	0.23	0.61***			
Length of bilingual experience[d]	0.70***	0.08	−0.79***	0.13	−0.23	0.12	−0.001	0.11		
No variability condition	−0.07	−0.06	0.13	0.3	−0.25	0.01	−0.2	−0.28	−0.05	
High variability condition	0.34*	0.03	−0.32	0.24	0.05	0.21	0.14	0.24	0.39*	0.14

[a]Visual Matrices subtest, *Kauffman Brief Intelligence Test – 2nd Edition*
[b]Highest Core Language Index Score from *Clinical Evaluation of Language Fundamentals – 5th Edition* (CELF-5) or *Clinical Evaluation of Language Fundamentals – 4th Edition, Spanish* (CELF-4 Spanish)
[c]*Expressive One-Word Picture Vocabulary Test – 4th Edition (EOWPVT-4); Expressive One-Word Picture Vocabulary Test – 4th Edition, Spanish-Bilingual Edition* (EOWPVT-4 SBE) for Spanish dominant children
[d]Length of time children were exposed to English and Spanish concurrently; Age of second language acquisition - Children's current age.
[e]NV = No Variability Condition

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Table 3. Average frequency and duration characteristics for speakers by condition for orders A and B

	Fundamental frequency (F0, Hz)	Minimum pitch (Hz)	Maximum pitch (Hz)	Word duration (seconds)
No variability condition				
Female speaker 1	256.90	158.66	278.09	0.97
Female speaker 2	218.70	166.61	271.62	1.07
High variability condition				
Female speaker 3	232.50	171.22	251.11	0.98
Female speaker 4	223.80	151.12	297.63	1.15
Female speaker 5	238.80	185.66	258.79	1.06
Female speaker 6	239.10	189.38	252.53	1.16
Female speaker 7	224.60	178.29	246.88	0.84
Female speaker 8	251.88	169.25	290.05	1.17
Female speaker 9	212.11	167.57	273.99	0.97
Female speaker 10	208.42	156.46	212.83	1.04
Female speaker 11	245.72	169.88	267.42	0.93
Female speaker 12	211.88	167.50	228.39	1.10
$Mean_{Females}$	**228.88**	**170.63**	**257.96**	**1.04**
Male speaker 1	123.77	117.36	130.39	1.00
Male speaker 2	114.44	109.96	119.79	0.87
Male speaker 3	121.09	85.86	126.09	1.03
Male speaker 4	123.87	87.43	142.35	0.97
Male speaker 5	110.98	92.61	124.80	0.72
Male Speaker 6	145.62	85.65	158.04	0.90
Male speaker 7	123.68	103.18	145.30	1.01
Male speaker 8	106.81	78.60	113.31	0.91
Male speaker 9	128.94	114.61	132.47	0.85
Male speaker 10	115.72	102.77	127.64	0.93
$Mean_{Males}$	**121.49**	**97.80**	**132.02**	**0.92**
Testing speaker				
Female speaker 13	222.40	183.49	233.16	0.89

learnability of the novel words. We indeed observed this trend in our sample where, as a group, participants were exposed to English about 60% of the time during their waking hours.

Stimuli. Two lists of 5 English-like novel words were retrieved from the Gupta et al. (2004) database. Novel words consisted of English phonemes, followed a common English-language phonotactic structure (i.e., CVCVC), and were produced by monolingual English-speakers. The Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Densities (CLEARPOND) Database (Marian et al., 2012) was used to compute English and Spanish biphone probability for each word. Words were combined into lists, and pairwise comparisons indicated that there were no significant differences in English or Spanish biphone probability within and across word lists. See Table S1 in Supplemental Materials for the lists of target words, biphone probabilities, and pairwise comparisons.

Novel colorful objects were selected from the Horst and Hout (2016) Novel Object & Unusual Name (NOUN) Database 2nd Edition and were paired with each novel word. Novel objects across lists were matched on familiarity scores and name-ability scores. Word-object pairs were counter-balanced across conditions. See Appendix A for the lists of word-object pairings by order and condition.

Conditions. The two experimental conditions were: no variability condition, where children were exposed to one exemplar labeled by one female speaker, and high variability condition, where children were exposed to three exemplars of each category labeled by 5 male and 5 female speakers. In this condition, each production of a word was labeled by a different speaker. Children were exposed to different speakers and objects in each condition and condition order was counterbalanced across participants.

Exemplars. Categories consisting of three object exemplars were selected from the NOUN Database (Horst & Hout, 2016). Objects in each category varied in their physical attributes (i.e., size, shape). We created one additional exemplar in PowerPoint by altering an existing exemplar by color. Three objects in each category were randomly assigned as either exposure items or the test item.

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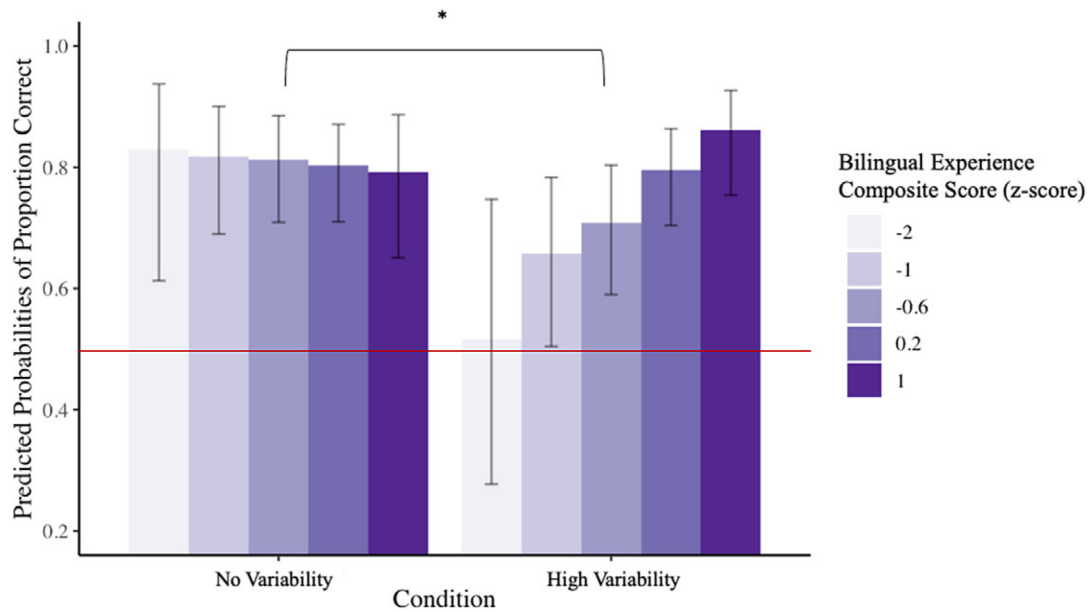

Figure 1. Condition and bilingual experience composite score interaction.
Note: Fitted model values for the Condition X Bilingual Experience Composite Score interaction term in the full model. Red line depicts chance levels (i.e., .50).
* p <. 05.

Speakers. Novel words were produced by 23 native English speakers from different regions in the United States between the ages of 18–40. Speakers included 13 females and 10 males. See Table 3 for average frequency and duration characteristics for each speaker.

Procedure. The XSWL task consisted of an exposure phase and a test phase. In each exposure phase, children were exposed to five novel word-object pairs and were instructed to look, listen, and learn the names of new toys (i.e., novel objects). Instructions were only presented once at the beginning of each condition. In each condition, every word-object pair was presented ten times in a pseudorandomized order across 25 trials. Each word-object pair appeared with every other word-object pair during the exposure phase. See Table S2 in Supplemental Materials for a list of example trials.

In each exposure trial, children were exposed to two novel words and two novel objects that were right-centered and left-centered at trial onset (i.e., 0 ms). Each exposure trial was approximately 6000 ms. The first novel word was produced at trial onset (i.e., 0 ms). The second novel word was produced 2000 ms after trial onset. The first word produced in each trial did not always label the left-centered object. Critically, no information about which word labeled which object was provided at any point during the exposure phase.

The testing phase followed immediately after the completion of the exposure phase. Test instructions were presented once at the beginning of the test phase. Novel exemplars that varied by color and/or shape from exposure exemplars were used during the test phase; these exemplars were not seen at any time during the exposure phases. Similarly, all target words at the test were produced by a different female speaker not heard during the exposure phases. In each condition, word-object associations were tested in a total of 10 testing trials via a 2-alternative force choice display. Each word-object pair was tested twice and served as a foil twice. A 500 inter-stimulus-interval was presented before each test trial. Each test trial was approximately 8000 ms. In each test trial, the target word was produced once at 2100 ms, and response buttons immediately appeared around the novel objects. Participants had 4000 ms after word onset to select a novel object. The number of exposure trials and test trials were the same across conditions. See Appendices B and C for methodological details.

2.5. Analyses

Two separate logistic mixed effects models were constructed in RStudio, version 1.2.5001 (RStudio Team, 2019) using the lme4 package (Bates et al., 2015) to examine the extent to which predictors increased or decreased children's likelihood (log-odds) of making an accurate response. In two separate models, accuracy data was regressed on condition (contrast coded, (−.5, .5); no variability versus high variability), language ability composite scores, bilingual experience composite scores, and their interactions with condition. Models were fitted with the maximum random effect structure (Barr et al., 2013). However, by-item random slopes and by-item random intercepts were removed in a stepwise fashion to resolve singularity and convergence issues (Brauer & Curtin, 2018). Final models included by-subject random intercepts and by-subject random slopes for Condition.

3. Results

Results revealed that children learned word-object pairs above chance levels (i.e., .50) in the no-variability condition (M = 0.75, SD = 0.23; *Range*: 0.30–1.00; $t(36) = 6.78$, $p < .001$), and high variability condition (M = 0.72, SD = 0.24; *Range*: 0.30–1.00; $t(36) = 5.52$, $p < .001$). Twenty-eight participants (76% of the sample) scored above chance in the no variability condition, and 27 participants (73%) scored above chance in the high variability condition. Different children scored above chance in each condition.

Logistic mixed effects model results revealed a significant interaction between condition and bilingual experience composite score

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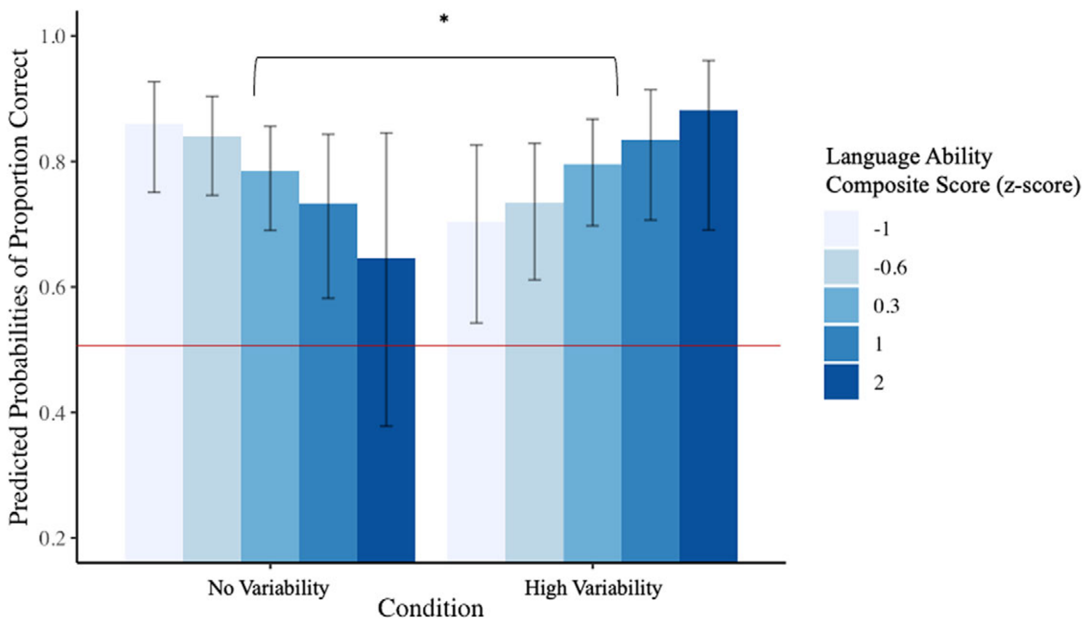

Figure 2. Condition and language ability composite score interaction.
Note: Fitted model values for the Condition X Language Ability Composite Score interaction term in the full model. Red line depicts chance levels (i.e., .50).
* *p* <. 05.

Table 4. Full model results for bilingual experience composite score analysis

	B (*SE*)	z	Odds ratio	95% CI
Intercept	1.33 (0.19)	7.14	3.77	2.62–5.43
Condition	− 0.18 (0.32)	− 0.56	0.84	0.45–1.57
Bilingual experience composite score	0.25 (0.19)	1.32	1.29	0.88–1.88
Condition X bilingual experience composite score	0.67 (0.33)	2.05*	1.95	1.03–3.69

**p* <. 05

Table 5. Full model results for language ability composite score analysis

	B (*SE*)	z	Odds Ratio	95% CI
Intercept	1.33 (0.19)	7.06	3.77	2.61–5.45
Condition	− 0.17 (0.31)	− 0.54	0.84	0.46–1.56
Language composite score	− 0.01 (0.20)	− 0.07	0.99	0.66–1.47
Condition X language composite scores	0.78 (0.34)	2.33*	2.19	1.13–4.24

**p* <. 05

(B = 0.67, SE = 0.33, z = 2.05, p < .05; *Odds Ratio:* 1.95, *95% CI:* 1.03–3.69) (Figure 1). Children with more bilingual experience were 1.95 times more likely to learn word-object pairs when variability was present in the input than children with less bilingual experience. A significant interaction between condition and language ability composite score was also observed, such that compared to children with weaker language abilities, children with robust language abilities were 2.19 times more likely to learn word-referent pairs when variability was present in the input compared to no variability ($B = 0.78$, $SE = 0.34$, $z = 2.19$, $p < .05$; *Odds Ratio:* 2.40, *95% CI:* 1.13–4.24) (Figure 2). Main effects of condition, bilingual language experience, and language ability were not significant (*ps* > .05). See Tables 4 and 5 for full model results.

To interpret the significant interactions, the simple effects of bilingual experience and language experience were tested at each level of condition via a logistic regression model using the generalized linear model function. Bilingual experience did not predict XSWL in the no-variability condition ($z = -0.08$, $p = .75$), but did so in the high condition ($B = 0.58$, $SE = 0.25$, $z = 2.38$, $p = .02$; *Odds Ratio:* 1.79, *95% CI:* 1.11–2.90). That is, children with more bilingual experience demonstrated better learning in the high variability condition compared to children with less bilingual experience.

Language ability did not significantly predict children's XSWL in the no variability condition ($z = -1.58$, $p = .11$) nor in the high variability condition ($z = 0.37$, $p = .27$), suggesting that the significant interaction captured the difference in slopes across conditions in children with no and high language ability composite scores. Specifically, children with more robust language abilities demonstrated better learning in the high variability condition compared to the no variability condition, whereas children with weaker language abilities learned better in the no variability condition compared to the high variability condition.

4. Discussion

In the present study, we examined the effects of variability on XSWL performance in bilingual school-aged children with a wide range of language abilities. A strength of our study was that bilingualism – a complex multidimensional construct – was measured continuously, capturing a fuller range of diverse linguistic experience. Children's language abilities were also measured continuously and across their two languages, allowing us to circumvent methodological issues associated with identifying language impairment in children with diverse histories. Results revealed graded effects of

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bilingualism and language ability on XSWL performance under increased input variability. Together, the results suggest that variation in the input and variation in the learner interact and modulate lexical learning.

Our results align with findings from a small but growing number of studies suggesting that the effects of bilingual experience on statistical learning performance may be conditional and depend on the properties of the input (e.g., Benitez et al., 2016; Poepsel & Weiss, 2016). Bilingual experience did not broadly impact how children disambiguated word-referent mappings during XSWL. However, children with more bilingual experience displayed similar levels of performance in the presence and absence of input variability, while performance decreased in the high variability condition for children with less bilingual experience. The exact mechanism underlying performance under increased variability in the current study is unclear and untested. One reasonable hypothesis is that variability increased demands on attentional effort. Enhancements in attention control then may have supported word-learning in children with more bilingual experience (e.g., Sorge et al., 2017; Chung-Fat-Yim et al., 2020). Future research is needed to identify cognitive mechanisms that support accommodating variable input during XSWL. Whatever the mechanism tapped by our variability manipulation, our findings suggest that the length of bilingual experience modifies lexical learning when variability is increased in the input in children with a range of language abilities.

In the present study, children with stronger language skills were also more likely to learn word-referent mappings than children with weaker language skills, especially in the high variability condition. These results suggest that for children with weaker language skills, variability in the input may thwart the discovery of co-occurring statistical regularities. This finding is consistent with previous work showing that, compared to children with robust language skills, performance in children with subclinical language weaknesses is disproportionately compromised when learning demands are heightened (e.g., Crespo & Kaushanskaya, 2022). If increased variability increased cognitive effort, then poorer performance in the high variability condition may have reflected subtle weaknesses in cognitive processing skills, like attention (e.g., Gandolfi & Viterbori, 2020; Marton, 2008; Pauls & Archibald, 2016). For children with stronger language skills, variability in the input boosted performance – in line with the variation theory of learning (e.g., Apfelbaum & McMurray, 2011; Restle, 1955) and with findings reporting facilitative effects of variability on other word-learning tasks (e.g., Rost & McMurray, 2010).

However, children's language ability composite scores did not predict their overall XSWL performance. This result is inconsistent with some previous work linking language and XSWL skills (e.g., Scott & Fisher, 2012). However, a relationship between language ability and XSWL performance has not always been observed (Vlach & Johnson, 2013; Vlach & DeBrock, 2017, 2019). For example, although language ability and XSWL were correlated, Vlach and DeBrock (2017, 2019) found that language ability did not predict children's XSWL performance over and above age. One possibility is that our composite approach to measuring language ability was at the root of the null finding regarding the relationship between language ability and XSWL. Using a similar method used in the current study, Crespo and Kaushanskaya (2022) also failed to find a significant main effect of language ability in a study examining children's rule induction. Perhaps standardized measures of receptive vocabulary skills (e.g., Vlach & DeBrock, 2017, 2019) and measures of overall language ability that capture lexical – semantic and morphosyntactic – syntactic skills in both expressive and receptive domains may not be indexing the *specific* linguistic skills necessary for XSWL. Future research is needed to examine how different methods of indexing language skills and their approximations of the processes indexed in statistical learning paradigms interact to influence the relationship between statistical learning performance and language ability.

One possible hypothesis, based on prior work (e.g., Creel & Jimenez, 2012; Crespo et al., 2023; Price & Sandhofer, 2021), is that input variability would increase learning demands and interfere with children's XSWL performance. We failed to find evidence supporting our interference hypothesis. Overall, children were equally likely to learn word-referent pairs in the no variability and high variability conditions. One reason for lack of variability effects is that accommodating multiple speakers and multiple object exemplars may not have been sufficiently challenging to influence learning and generalization, particularly on a receptive word-learning task. Another possibility, but not an inconsonant one, is that XSWL mechanisms may be "mature" enough to accommodate superficial variability in the input without influencing learning in school-aged populations. We see some supporting evidence for this theorizing in Crespo and Kaushanskaya (2021), who reported similar null findings of speaker variability on children's XSWL performance in a similar age range. Critically, although input variability was not sufficiently challenging to yield a main effect in our whole sample, it was sufficiently challenging to engender effects of bilingual experience and language ability on XSWL performance under increased variable input.

We acknowledge that a greater number of children with poor language skills would have been helpful to detect an effect of input variability on XSWL performance in the whole sample. The inclusion of children with lower language abilities in future studies, particularly children with a diagnosis of developmental language disorder, may be required to determine whether weaknesses in language ability are associated with weaknesses in XSWL under different variability manipulations. Larger samples of children on the lower end of the language ability continuum may also be required to better understand how bilingualism and language ability interact and shape mechanisms of language learning over time.

The present study examined how factors that impact the fidelity of the signal (i.e., variability) and factors that impact how the signal is processed (i.e., bilingual experience and language ability) interact to influence lexical learning. Together, our results suggest a differential effect of variability on XSWL performance depending on children's levels of bilingual experience and language ability. Given that natural language input is replete with variability, our findings suggest that variability might impose downstream consequences to vocabulary development, and this may be especially true for some children.

Supplementary material. To view supplementary material for this article, please visit http://doi.org/10.1017/S1366728924000592.

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Competing interest. The author(s) declare none.

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