

Input Variability and Word Learning in Children with Different Language Abilities

By

Kimberly A. Crespo

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The dissertation is approved by the following members of the Final Oral Committee:
Margarita Kaushanskaya, Professor, Communication Sciences and Disorders
Susan Ellis Weismer, Professor Emeritus, Communication Sciences and Disorders
Haley Vlach, Associate Professor, Educational Psychology
Jenny Saffran, Professor, Psychology

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Dedication

This dissertation is dedicated in loving memory to Laura Maria Ocampo, and to all the young people lost to the coronavirus pandemic.

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Abstract

Cross-situational statistical word learning (XSWL) - the ability to learn words by tracking co-occurrence statistics of words and their referents over time - is a fundamental mechanism underlying lexical acquisition. The current dissertation examined the effects of input variability on XSWL performance in children with diverse language abilities. Across three experiments, children learned novel word-referent mappings from multiple exemplar and multiple speaker input in XSWL tasks.

Experiment 1 examined the separate and combined effects of exemplar and speaker variability on XSWL performance in typically developing monolingual English-speaking children. Results showed that variability within a single dimension (i.e., exemplars or speakers) did not facilitate nor hinder children's XSWL performance. However, variability in multiple dimensions (i.e., exemplars and speakers) hindered word-learning in monolinguals. **Experiment 2** compared XSWL performance in Spanish-English bilingual children and English-monolingual children under different variability conditions. In line with findings from Experiment 1, variability in a single dimension (i.e., exemplars or speakers) did not influence children's XSWL performance. However, results revealed bilingual word-learning advantages in conditions that varied in multiple dimensions (i.e., exemplars and speakers). Overall, bilinguals were more likely to learn word-referent associations than monolinguals when variability was present in the input. **Experiment 3** examined the role of language ability and length of bilingual experience in XSWL performance under low and high variability conditions in Spanish-English bilingual children. Results demonstrated graded effects of language ability and bilingual experience on XSWL performance under conditions of increased variability. When the input varied in multiple

dimensions (i.e., exemplars and speakers), word-learning performance significantly decreased as children's language skills decreased and length of bilingual experience decreased.

Together, findings from this dissertation suggest that children can learn and generalize word-referent associations from input that varies in exemplars and speakers. However, accommodating multiple dimensions of variable input (a common occurrence in natural language environments) may have distinct consequences for word-learning outcomes depending on children's language abilities. Results from the current work may inform future research and clinical approaches focusing on how best to structure language input to optimize language outcomes for all children.

Chapter 1: General Introduction

Statistical learning is defined as the ability to detect and encode structured patterns in the environment without trying to learn and without becoming aware that learning occurred (e.g., Saffran, Aslin, & Newport, 1996). Statistical learning is considered a domain-general mechanism, one that has been implicated in the development of both non-linguistic (e.g., Kirkham, Slemmer & Johnson, 2002; Liao & Masters, 2001; Saffran, Johnson, Aslin, & Newport, 1999; Saffran, Pollak, Seibel, & Shkolnik, 2007) and linguistic skills (e.g., Onnis, Christiansen, Charter & Gómez, 2003; Romberg & Saffran, 2010; Saffran et al., 1996). Research has also shown that humans across the lifespan are sensitive to structural regularities in their environment, from early infancy (e.g., Bulf, Johnson, & Valenza, 2011; Hay, Pelucci, Graf Estes & Saffran, 2011) into adulthood (e.g., Asmo & Davidow, 2012) across different modalities (e.g., audio, visual, tactile; Conway & Christensen, 2005) and input types (e.g., adjacent and non-adjacent transitional probabilities, co-occurring regularities; Saffran et al., 1996; Newport & Aslin, 2004; Yu & Smith, 2007).

This dissertation focuses on the learning of co-occurring regularities between words and their labels via cross-situational word learning (XSWL) – a powerful statistical learning mechanism underlying lexical acquisition (Yu & Smith, 2007). XSWL, and statistical learning theory broadly, has seldom been examined against the natural characteristics of the input children receive. In natural learning contexts, children are exposed to variability in perceptual properties of objects (e.g., big cup, blue cup) and input from multiple speakers (e.g., both mom and dad saying “cup”). To fully understand the role of XSWL in language acquisition, we must understand how input variability impacts children’s ability to learn word-referent mappings. We must also consider how individual differences in language experience and language ability

interact with input variability to influence word-learning outcomes. Therefore, the overarching goal of this dissertation was to determine the effects of input variability on XSWL performance in children with different language histories and language abilities within the normal range.

In this dissertation, variability was experimentally manipulated in two dimensions: speaker identity and category structure. **Aim 1** of this work was to examine the separate and combined effects of speaker and exemplar variability on XSWL performance in monolingual English-speaking children (Experiment 1). **Aim 2** was to examine the effects of bilingualism on XSWL under the different variability conditions. To accomplish Aim 2, word-learning performance in bilingual children was compared to word-learning performance in demographically matched monolingual children (Experiment 2). Further, XSWL was examined in bilingual children only and we tested whether individual differences in bilingual experience, language ability, or both moderated XSWL performance in low and high variability conditions (Experiment 3).

Speaker and Exemplar Variability

Statistical learning mechanisms are sensitive to variability. Studies have shown that learning in conditions of high variability, compared to conditions of low variability, supports the detection of statistical regularities in infants (Gómez, 2002; Graf Estes & Lew-Williams, 2015), children (Suanda, Mugwanya, & Namy, 2014), and adults (Gómez, 2002; Yu & Smith, 2007). Gómez (2002) theorized that facilitative effects of variability on statistical learning performance suggest that learners are dynamically guided by structure. That is, learners may be driven to seek out regularities that are predictable and invariant. Consequently, attention may be shifted from structures that vary and yield weak statistical regularities, to invariant structures that yield stronger, more stable statistical regularities. This concept is formalized in the variation theory of

learning, a theory that centers on variation as a key mechanism for structure discovery (Apfelbaum, & McMurray, 2011; Gibson & Gibson, 1955; Marton, 2015). Specifically, the theory posits that variation of irrelevant features highlights target structures making targets easier to detect and learn (Apfelbaum, & McMurray, 2011; Gibson & Gibson, 1955; Marton, 2015). The variation theory of learning has not been explicitly linked with findings in the statistical learning literature. However, researchers in the explicit learning literature, where items are directly taught to learners, have grounded facilitative findings of variability in this theory (e.g., Rost & McMurray, 2010).

There is evidence to suggest that phonemic variability from multiple speaker input may also support word-learning and generalization (e.g., Apfelbaum & McMurray, 2011; Richtsmeier, Gerken, Goffman, & Hogan, 2009; Rost & McMurray, 2009; 2010; Höhle, Fritzsche, Meß, Phillip, & Gafos, 2020; Quam, Knight, & Gerken, 2017). Voice characteristics across different talkers vary systematically in pitch, resonance, intensity, and rate. Based on the variation theory of learning, fluctuations in speech productions across speakers may help learners to identify irrelevant cues, like talker-specific characteristics which vary across all speakers, from predictable structures, like acoustic boundaries differentiating similar-sounding word forms (e.g., Rost & McMurray, 2010). In a similar fashion, exemplar variability is theorized to foster broad category representations by highlighting the invariant features that are core to category membership (e.g., Ankowski, Vlach, & Sandhofer, 2013; Gentner, Loewenstein, & Hung, 2007; Mandler, Fivush, Reznick, 1987; Namy & Gentner, 2002). In both instances, speaker variability and exemplar variability enable the learner to establish broader representations, which in turn facilitates generalization.

Therefore, in both **Experiment 1** and in **Experiment 2**, we hypothesized that input variability may bolster children's encoding of novel word forms, and of features that determined object category membership, facilitating word-referent mapping during XSWL. Robust representations would then yield better generalization of word-referent mappings to a novel speaker and a novel object exemplar at test. Based on null findings in similar word-learning tasks, an alternative hypothesis was that variability in neither the speakers (e.g., Crespo & Kaushanskaya, 2021), nor the exemplars (e.g., Höhle et al., 2020), would influence children's XSWL. Yet another alternative hypothesis was that variability in a single dimension, particularly in speakers (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997), would hinder XSWL performance. The hypothesis was based on the robust findings from the psycholinguistics literature showing that speaker variability impairs speech processing in children (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997).

An open question is whether exemplar and speaker variability yield distinct consequences for learning when they are separated in the input, compared to when they are combined in the input. One possibility is that variation in multiple dimensions (i.e., exemplars and speakers) may create additional demands for processing, negatively impacting XSWL to a greater extent than variation in one dimension (i.e., exemplars or speakers). Studies have shown that increased input complexity may decrease statistical learning performance (e.g., Jost, Brill-Schuetz, Morgan-Short, & Christiansen, 2019; Yu & Smith, 2007; Toro, Sinnett, & Soto-Faraco, 2005; 2011). There is also evidence to suggest that statistical learning mechanisms may be sensitive to increased demands beyond those imposed by the complexity of the statistics-to-be-learned (Crespo & Kaushanskaya, 2022; Toro et al., 2005, 2011). For example, manipulations that increase attentional load have been shown to negatively impact statistical learning performance

(e.g., Crespo & Kaushanskaya, 2022; Toro et al., 2005, 2011). However, other studies have not observed evidence that complexity impacts statistical learning performance (e.g., Musz, Weber, & Thompson-Schill, 2015). Therefore, it remains unknown whether variability in multiple dimensions (i.e., speakers and exemplars) would confer computational advantages or disadvantages for children's XSWL.

In line with the variation theory of learning, it was hypothesized that the increased variability in multiple dimension (i.e., speakers and exemplars) would bolster children's word-learning performance to a greater extent than variability in a single dimension (i.e., speakers or exemplars). An alternative hypothesis was that variability in multiple dimensions (i.e., speakers and exemplars) would impair children's XSWL performance. A third hypothesis was that XSWL mechanisms might be immune to variability effects and scale to accommodate variability in a single and multiple dimensions without consequence to learning outcomes.

Bilingualism

There is a robust literature suggesting that bilingualism enhances word-learning performance (e.g., Alt, Arizmendi, Gray, Hogan, Green, & Cowan, 2019; Eviatar, Taha, Cohen, & Schwartz, 2018; Yoshida, Tran, Benitez, & Kuwabara, 2011; Kaushanskaya, Gross, & Buac, 2014; but see Alt et al., 2019; Alt, Meyers, & Figueroa, 2013; Buac, Gross, & Kaushanskaya, 2016; de Diego-Lázaro, Pittman, & Restrepo, 2021). Some scholars theorize that bilingual word learning advantages may stem from enhancements in phonological working memory (Eviatar et al., 2018; Kaushanskaya & Marian, 2009), and executive function skills, like inhibition – the ability to control attention and inhibit task-irrelevant information (e.g., Darcy, Mora & Daidone, 2016; Warmington, Kandru-Pothineni, & Hitch, 2019; Yoshida et al., 2011).

In the last decade, researchers have started to inquire if bilingualism influences statistical word learning via XSWL paradigms. To date, only four studies – three in adults and one in children – have examined the effects of bilingualism on XSWL performance (Benitez, Yurovsky, & Smith, 2016; Crespo & Kaushanskaya, 2021; Escudero, Mulak, Fu, & Singh, 2016; Poepfel & Weiss, 2016), and the pattern of results is mixed. Generally, findings suggest that bilingualism may not influence the development of core XSWL abilities (Benitez et al., 2016; Crespo & Kaushanskaya, 2021; Poepfel & Weiss, 2016, but see Escudero, et al., 2016). However, in adults, bilingual advantages in XSWL have been observed under conditions of increased complexity, such as mapping two words to one referent (e.g., Poepfel & Weiss, 2016). In children, monolingual XSWL advantages have been reported (Crespo & Kaushanskaya, 2021). Taken together, it remains unclear whether, and under what conditions, bilingualism influences XSWL mechanisms.

In **Experiment 2**, XSWL performance in demographically matched bilinguals and monolinguals was compared. There is growing evidence suggesting that bilingualism may promote the development of more flexible and efficient statistical learning abilities (e.g., Antovich & Graf Estes, 2018; Wang & Saffran, 2014). Kuo and Anderson (2012) proposed that bilinguals' habitual experience of detecting the parameters that separate their two languages fosters a superior sensitivity to linguistic structure – the structural sensitivity theory. It is plausible that this sensitivity to structure might make bilinguals especially adept at detecting more challenging linguistic statistical regularities in the input. Indeed, bilingual statistical learning advantages have been documented most consistently in paradigms that require the detection of multiple speech and rule structures (Antovich & Graf Estes, 2018; Kovács &

Mehler, 2009; Onnis, Chun & Lou-Magnuson, 2018; Wang & Saffran, 2014), as well as novel phonological patterns (Kuo & Anderson, 2012).

It is plausible that bilingual enhancements in the abilities to detect structure (e.g., Kuo & Anderson, 2012), inhibit (e.g., Yoshida et al., 2011), and process (e.g., Eviatar et al., 2018) relevant vs. irrelevant cues may facilitate XSWL. We hypothesized that if bilingual experience broadly enhances XSWL skills, then bilinguals would outperform monolinguals overall, in line with Escudero et al. (2016). However, if XSWL is not broadly influenced by bilingual experience, then bilinguals and monolinguals will perform equally well.

Bilingual children have been shown to be more skilled than monolingual children at sorting items by multiple dimensions (e.g., Bialystok, 1999; Bialystok & Martin, 2004), a cognitive skill that may be especially useful in accommodating multiple exemplars. Additionally, bilingualism may enhance talker-voice processing abilities (e.g., Levi, 2018). Therefore, we hypothesized that bilinguals may be especially competent at accommodating multiple exemplars and speakers, separately and when combined, during XSWL, compared to monolinguals. Alternatively, multiple exemplars and speakers may not impact XSWL performance, and in this case, monolinguals and bilinguals will perform similarly under different variability conditions.

Experiment 3 focused exclusively on bilinguals with the goal of examining how individual differences in children's language ability and length of bilingual experience contributed to accommodating input variability. Examining the effects of bilingualism continuously, in addition to categorically (bilinguals vs. monolinguals; **Experiment 2**), is theoretically interesting because, within a population characterized by immense heterogeneity, it allows us to determine which aspects of bilingual experience impact XSWL. Indeed, recent research has urged the use of more continuous approaches to defining bilingualism to advance

our understanding of its consequences on language and cognition (e.g., de Bruin, 2019; Kaushanskaya & Prior, 2015; Kremin & Byers-Heinlein, 2021; Marian & Hayakawa, 2020; Takahesu Tabori, Mech, & Atagi, 2018).

Experiment 3 focused on comparing XSWL performance in a low variability condition (i.e., no variability) to a high variability condition (i.e., variability in exemplars and speakers). Examining word learning performance with variability in multiple dimensions (i.e., exemplars and speakers), relative to no variability, allowed the experiment to focus on learning under increased complexity over and above exemplar-specific or speaker-specific effects (**Experiment 1** and **Experiment 2**). It was hypothesized that if effects of bilingualism on XSWL are specific to conditions of increased complexity, then XSWL performance in the high variability condition will increase with increases in bilingual experience. Alternatively, if exposure to variable input does not impact XSWL performance, then children would perform equally well in low and high variability conditions independent of their bilingual experience.

Language Ability

Studies in monolingual English-speaking children have shown that individual differences in language ability predict individual differences in XSWL performance (e.g., Hartley, Bird, & Monaghan, 2020; McGregor, Smolak, Jones, Oleson, Eden, Arbisi-Kelm, & Pomper, 2022; Scott & Fisher, 2012; Vlach & Debrock, 2017; 2019). The general pattern of findings is that children with stronger language skills outperform children with weaker language skills, both within the normal range of language ability (e.g., Scott & Fisher, 2012; Vlach & Debrock, 2017; 2019) and across typically developing versus language-impaired populations (Hartley et al., 2020; McGregor et al., 2022).

Unlike monolingual children, bilingual children are exposed to two languages. However, the development of those two languages is not linear. Bilingual children experience fluctuations in their language-specific skills over time as a function of exposure and experience/use. In this dissertation, a composite score, instead of a single assessment score, was used to capture the overall robustness of the linguistic system without penalizing children for weaknesses in English- or Spanish-specific skills. Specifically, children's highest language and vocabulary scores from different standardized assessments in English and/or Spanish were combined into a composite score.

A continuous approach, versus a categorical approach, was used to define language ability, taking advantage of the fact that the bilingual sample included language composite scores in the poor-to-above-average range. Examining language ability as a continuum is arguably a theoretically, and an analytically, more robust strategy than a group-comparison approach given the methodological issues associated with identifying language impairment in bilingual populations (e.g., Bishop, 2017; Morgan et al., 2015; Samson & Lesaux, 2009). It was hypothesized that if XSWL is sensitive to weaknesses in language abilities within the normal range (i.e., in the absence of formal language impairment diagnoses), then bilingual 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 bilingual children will learn word-referent pairings similarly independent of language ability.

Of particular interest was the question of whether exposure to variability in multiple dimensions would disproportionately impact XSWL in children with lower levels of language ability. Studies have shown that, like children with Developmental Language Disorder (DLD), children with weak language skills have difficulties ignoring irrelevant cues during learning and

display subtle weaknesses in selective attention skills (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 diagnoses, displayed difficulties learning statistical regularities for artificial rules under increased attention demands (Crespo & Kaushanskaya, 2022). If accommodating input variability is taxing, then we hypothesized that XSWL performance in the high variability condition would increase as children's language abilities increased.

The Current Dissertation

Aims

Research has shown that children can discover relationships between words and meanings in ambiguous scenarios by aggregating co-occurring statistics over time – a process termed via cross-situational word learning (XSWL). To date, research examining XSWL mechanisms has focused on word-referent mapping in monolingual English-speaking persons exposed to input devoid of variability. In the real world, language input is replete with speaker and exemplar variability. Upon learning a word, children must successfully generalize the word's meaning to novel object exemplars and productions by novel speakers. Research examining XSWL has also seldom examined how individual differences in language experience and language ability contribute to XSWL. Consequently, it remains unknown how variability in the input, and individual differences in bilingual experience and language ability, interact and influence XSWL performance. In the current dissertation, the effects of variability on XSWL under different variability conditions were examined in a linguistically diverse sample of school-aged children with a wide range of language abilities.

The goals of the dissertation were:

1. To examine the separate and combined effects of exemplar and speaker variability on XSWL performance in monolingual children (Experiment 1)
2. To examine the effects of bilingualism on XSWL performance under different variability conditions by comparing bilinguals to monolinguals (Experiment 2) and by examining individual differences in bilingual experience and language ability in bilinguals only (Experiment 3).

Population

These aims were addressed in a series of three experiments that utilized the same sample of 5 – 8-year-old English monolingual and Spanish-English bilingual children. Participants included a total of 71 typically developing children: 34 English monolinguals and 37 Spanish-English bilinguals. Exclusionary criteria consisted of a history of psychiatric, neurological and/or intellectual disability. On average, bilingual children were first exposed to English and Spanish by twelve months of age. Monolinguals and bilinguals were matched on age, mother's years of education (proxy for SES), nonverbal IQ, and English language skills (indexed by the Core Language Index Score from Clinical Evaluation of Language Fundamentals – 5th Edition (CELF-5); Wiig, Semel, & Secord, 2013) ($ps > .05$).

Methodology

All study sessions were conducted on Zoom. Children learned English-like novel words in a XSWL task in four conditions: (1) No Variability Condition, where children saw one exemplar of each category labeled by one speaker; (2) Multiple Speaker Condition, where children saw one exemplar of each category labeled by ten speakers; (3) Multiple Exemplar Condition, where children saw three exemplars of each category labeled by one speaker; and (4)

Combined Variability Condition, where children saw three exemplars of each category labeled by ten speakers. Learning was measured via a 2-alternative-forced choice task where children were instructed to select an object corresponding to the target word. Children also completed standardized measures of language, expressive vocabulary, and non-verbal IQ.

Overview

The next three chapters in the current dissertation include three empirical papers addressing Aims 1-3. Chapter 2 is titled, “The effects of speaker and exemplar variability in children’s cross-situational word learning” and focuses on XSWL in monolingual children (Experiment 1; Aim 1). Chapter 3 is titled, “The effects of bilingualism on XSWL performance under different variability conditions” and focuses on XSWL in bilingual vs. monolingual children (Experiment 2; Aim 1 & 2). Chapter 4 is titled, “The graded effects of bilingualism and language ability on children’s XSWL performance under low and high variability conditions” and focuses on individual differences in XSWL performance. The last chapter, Chapter 5, is a General Discussion of the findings across the three papers.

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Chapter 2: The effects of speaker and exemplar variability in children’s cross-situational word learning

Abstract: Cross-situational word learning (XSWL) – children’s ability to learn words by tracking co-occurrence statistics of words and their referents over time – has been identified as a fundamental mechanism underlying lexical learning. However, it is unknown whether children can acquire new words when faced with variable input beyond word-referent associations, such as varying exemplars and speakers. In the present study, we examine the separate and combined effects of exemplar and speaker variability on XSWL in typically developing English-speaking monolingual children. Results revealed that variability in speakers and exemplars did not facilitate or hinder XSWL performance. However, input that varied in both speakers and exemplars simultaneously did hinder children’s word learning. Results from this work suggest that XSWL mechanisms may support categorization and generalization beyond word-object associations, but that accommodating multiple forms of variable input may incur costs. Overall, this research provides new theoretical insights into how fundamental mechanisms of word learning scale to more complex and naturalistic forms of input.

Introduction

Children typically hear words in the context of multiple potential referents. Research has shown that learners can contend with referential ambiguity by tracking co-occurrence statistics of words and their referents over time, a statistical learning mechanism termed cross-situational word learning (XSWL; Yu & Smith, 2007). In a typical paradigm, participants are presented with multiple pictures of objects simultaneously in each trial. Multiple words are played sequentially in a random order, such that it is unclear which word refers to which object. Word-object pairs appear with a different set of words and objects across trials. Children track these co-occurrence statistics and use them to infer word-object mappings at a post-test. In addition to experimental work (e.g., Smith & Yu, 2008; Suanda, Mugwanya, & Namy, 2014; Vlach & Johnson, 2013; Yu & Smith, 2007), computational models have shown that XSWL is a viable mechanism that can emulate word-object mappings from small (e.g., Roembke & McMurray, 2016; Yu & Smith, 2012) but realistic language corpora as well as large, language-scale lexicons (Blythe, Smith, & Smith, 2010).

In real-world contexts, other forms of variability in the input exist beyond word and object co-occurrences. The speaker and objects are two key sources of variability; children are exposed to words from multiple speakers (e.g., both mom and dad saying “cup”) as well as to objects that vary in their perceptual properties (e.g., big cup, blue cup). However, past research has not examined whether children can encode multiple forms of variability simultaneously during XSWL. Consequently, it is unknown how input variability influences the uptake of co-occurrence data. Therefore, the goal of the present study was to determine the separate and combined effects of exemplar and speaker variability on children’s XSWL performance.

Exemplar and Speaker Variability in Language Learning

Variability has been historically characterized as critical to successful learning. These facilitative effects of variability have been linked to the variation theory of learning, which has been extensively examined as an instructional design principle in the education literature (e.g., Gibson & Gibson, 1955; Marton, 2015) and in category formation in the field of cognitive psychology (e.g., Ankowski, Vlach, & Sandhofer, 2013; Gentner, Loewenstein, & Hung, 2007; Mandler, Fivush, & Reznick, 1987; Namy & Gentner, 2002). Classical theories of categorization posit that exposure to multiple exemplars allows learners to abstract the invariant features of a category, which fosters more broad category representations, and thus facilitates generalization of words (e.g., Mandler et al., 1987). Experimental work has corroborated this theorizing, showing that exposure to highly variable object category members facilitates category name generalization and retention (e.g., Ankowski et al., 2013; Gentner et al., 2007; Namy & Gentner, 2002; Perry, Samuelson, Malloy, & Shiffer, 2010; Twomey, Ranson, & Horst, 2014). There is also evidence to suggest that adults can use cross-situational statistics to simultaneously learn category level and basic level names for objects via XSWL, with some constraints observed for

generalization (e.g., Chen, Gershkoff-Stowe, Yu, Cheung, & Yu, 2017; Chen, Zhang, & Yu, 2018; Gangwani, Kachergis, & Yu, 2010).

The use of multiple exemplars of novel objects in the present study allowed us to examine the extent to which XSWL mechanisms support the detection and abstraction of common features across object categories, and to test how this process impacts statistical word-object learning in children. Variability also appears to be important for learning auditory categories. People's voices systematically vary in pitch, resonance, intensity, and rate. In explicit learning paradigms, speaker variability has been found to confer superior phoneme discrimination (Baese-Berk, Bradlow, Wright, 2013; Bradlow & Bent, 2008; McClelland, Fiez & McCandliss, 2002), word learning (e.g., Apfelbaum & McMurray, 2011; Richtsmeier, Gerken, Goffman, & Hogan, 2009; Rost & McMurray, 2009; 2010; Höhle, Fritzsche, Meß, Phillip, & Gafos, 2020; Quam, Knight, & Gerken, 2017) and generalization (e.g., Rost, McMurray, 2009; 2010). Experimental evidence (Galle, Apfelbaum, & McMurray, 2015; Rost & McMurray, 2009; 2010), in conjunction with modeling findings (Apfelbaum & McMurray, 2011), has provided some evidence for the thesis that greater phonemic variability in the acoustic signal may support word learning, particularly when phonetic categories are not fully developed.

While facilitative effects of variability in objects and speakers are likely, interference effects are also plausible. Interference effects of speaker variability have been documented on perceptual and learning tasks (e.g., Creel & Jimenez, 2012; Goldinger, Pisoni & Logan, 1991; Kishon-Rabin, Taitelbaum-Swead, Salomon, Slutzkin & Amir, 2009; Ryalls & Pisoni, 1997). Several models of speech processing posit that adjusting to multiple speaker input results in increased processing costs for speech perception (Bressler, Masud, S., Bharadwaj, & Shinn-Cunningham, 2014; Choi & Perrachione, 2019; Lim, Shinn-Cunningham, & Perrachione, 2019;

Magnuson & Nusbaum, 2007). Compared to adults, children are often disproportionately impacted by speaker variability due to underdeveloped talker normalization processes (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997). Therefore, we also considered the possibility that additional variance in novel word forms might interfere with how children converge on novel word representations, compounding the difficulty of disambiguating word-object mappings over time during XSWL.

To date, only two studies have examined the effects of speaker variability on XSWL (Crespo & Kaushanskaya, 2021; McGregor, Smolak, Jones, Oleson, Eden, Arbisi-Kelm, & Pomper, 2022). McGregor et al. (2022) demonstrated that children with and without language impairment successfully disambiguated word-referent mappings during XSWL when exposed to multiple speakers. However, children's word learning performance was not compared to a single speaker condition, and thus it is unknown whether there was a cost to the speaker variability. Crespo and Kaushanskaya (2021) found that exposure to multiple speakers neither facilitated nor hindered word learning. In the Crespo and Kaushanskaya (2021) study, 10 female speakers were presented in the multiple speaker condition, and in the present study, we exposed children to both female and male speakers in the multiple speaker condition. We reasoned that including male speakers in addition to female speakers may create more acoustic variability, and yield an effect of speaker variability, if such an effect exists. We reasoned that including male speakers in addition to female speakers may create more acoustic variability, and yield an effect of speaker variability, if such an effect exists. In addition to examining the effects of speaker variability on XSWL, a crucial question for the present study was whether speaker variability would interact with exemplar variability in influencing XSWL.

The degree to which variability across multiple dimensions simultaneously influences XSWL is an open question. Adult learners have been shown to acquire statistical information in both visual and auditory domains concurrently when the input is organized sequentially (Conway & Christiansen, 2005; Mitchel, Christiansen, & Weiss, 2014; Mitchel & Weiss, 2011; van den Bos, Christiansen, & Misyak, 2012) and cross-situationally (e.g., Chen et al., 2017; Chen et al., 2018; Gangwani et al., 2010). However, young monolingual infants appear to struggle with learning of multiple structures simultaneously in statistical learning tasks (e.g., Bulgarelli, Benitez, Saffran, Byers-Heinlein, & Weiss, 2017). Thus, the central research question in this work was: How would school-age children, who are cognitively more advanced than infants, but less cognitively mature compared to adults, learn from input that varies in category structure and speakers simultaneously during XSWL?

Current Research

As reviewed above, the separate and combined effects of exemplar and speaker variability may have distinct consequences for learning. Accommodating variability in one dimension (i.e., exemplars or speakers) may be easier for children than accommodating variability in two dimensions (i.e., exemplars and speakers). Due to developmental limitations in children's processing capacity (e.g., Bauer, Martinez, Roe, & Church, 2017) and statistical learning abilities (e.g., Arciuli & Simpson, 2011; Arciuli & von Koss Torkildsen, 2012; Janacsek, Fiser, & Nemeth, 2012; Lukács & Kemény, 2015; Shufaniya & Arnon, 2018), it is possible that variability in multiple cues may place additional processing demands on disambiguating word-object pairs, hindering children's word learning. Based on the two studies on speaker variability in children's XSWL and research on developmental constraints, we predicted that speaker variability or exemplar variability alone would not affect children's

XSWL performance. However, we predicted that including both forms of variability would deter children's XSWL. Therefore, an alternative hypothesis is that simultaneous exposure to multiple exemplars and speakers may bolster the process of disambiguating word-object pairs, producing a facilitatory effect on XSWL. In this instance, performance in the combined variability condition may be superior to performance in conditions where children are exposed to only multiple exemplars or multiple speakers. The current experiment was designed to test these two competing hypotheses.

Methods

This study was reviewed and approved by the Education and Social/Behavioral Science Institutional Review Board at the University of Wisconsin-Madison. Participants' legal guardians provided informed consent and children provided oral assent. All data collection was conducted remotely via Zoom.

Participants

Thirty-seven English monolingual children ages 5 – 8 were recruited and tested in 2 to 3 1-hour long sessions. Two participants were excluded because they could not engage with testing tasks via Zoom. One participant was also excluded because they failed to return for a second session to complete study tasks. The final sample included 34 children ($M_{\text{age}} = 6.87$; 20 girls). Exclusionary criteria consisted of 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). All children acquired English from birth and reported less than 5% consistent exposure to other languages at any time. Information about mother's years of education as proxy for SES was collected through the Language Experience

and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 2007). See Table 1 for participant characteristics.

Table 1. Participant Characteristics

	<i>Mean</i>	<i>SD</i>	<i>Range</i>
Age (years)	6.86	1.07	5.08 – 8.83
Mother's years of education	16.96	1.97	13 – 22
Non-verbal IQ ^a	111.97	16.23	74 – 144
Core Language Index ^b	108.18	13.93	81 – 141

^a Standard Score; Visual Matrices subtest of the Kaufman Brief Intelligence Test (KBIT-2)

^b Standard Score; Clinical Evaluation of Language Fundamentals-Fifth Edition (CELF-5)

Experimental Task

XSWL tasks were hosted on Gorilla (<https://gorilla.sc>), an online platform that allows researchers to build experiments online. Each child completed a XSWL task in four experimental conditions in a within-subject design.

Stimuli. Four lists of 5 English-like novel words matched on English biphone probability and neighborhood density were created for each condition (Gupta Lipinski, Abbs, Lin, Aktunc, Ludden, Martin, & Newman, 2004). Two lists of 5 individual novel objects and two lists of 5 categories were created using the catalog of objects from the Horst & Hout (2016) Novel Object & Unusual Name (NOUN) Database 2nd Edition. Object lists were matched on familiarity and name-ability scores (Horst & Hout, 2016). Each novel word was paired with a novel object and lists of word-object pairs were counter-balanced across condition. See Appendix A for the lists of word-object pairings by order and condition.

Exemplars. Each object category had 4 exemplars that varied in terms of their physical attributes (i.e., size, color, shape); three exemplars were provided by the NOUN Database (Horst

& Hout, 2016) and one exemplar was created in PowerPoint by altering the image color.

Database images and PowerPoint-created images were randomly assigned to serve as either an exposure or test item.

Speakers. Twenty-three native English speakers from different regions in the United States between the ages of 18 – 40 recorded the novel words. This included 13 female speakers and 10 male speakers. See Table 2 for average frequency and duration characteristics for each speaker.

Design. The four within-subjects experimental conditions were: 1. No Variability Condition, where children were exposed to one exemplar labeled by one female speaker; 2. Multiple Exemplar Condition, where children were exposed to three exemplars of each category labeled by one female speaker; 3. Multiple Speakers Condition, where children were exposed to one exemplar labeled by 5 male and 5 female speakers. In this condition, each production of a word was labeled by a different speaker; and 4. Combined 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 also labeled by a different speaker. Critically, children were exposed to different speakers, objects, and categories in each condition. Condition order was counterbalanced across participants.

Procedure. Children were exposed to 5 word-object pairs in each XSWL condition. The XSWL task consisted of an exposure phase and a test phase. In the exposure phase, children were instructed to look, listen, and learn the names of new toys (i.e., novel objects). Each word-object pair was presented ten times in a pseudorandomized order across a total of 25 trials. In each trial, two novel objects were displayed (right-centered, left-centered). The order of word presentation and position of objects on the screen (i.e., right-left orientation) were counter-balanced. No

information about which novel word labeled which object was provided at any time during the exposure phase.

Table 2. Average Frequency and Duration Characteristics for Speakers by Condition

	Fundamental Frequency (F0, Hz)	Minimum Pitch (Hz)	Maximum Pitch (Hz)	Word Duration (seconds)
Single Speaker & Multiple Exemplar				
Female Speaker 1	256.90	158.66	278.09	0.97
Female Speaker 2	218.70	166.61	271.62	1.07
Multiple Speaker & Combined Cue				
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
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The testing phase followed immediately after the exposure phase for each condition and examined whether children learned correct word-object associations in a 2-alternative force choice display. Each word-object pair was tested twice, and served as a foil twice, in a total of 10 testing trials. Critically, all test objects were novel exemplars, and all target words were produced by a different female speaker not heard during any of the exposure phases. See Appendix B and C for methodological details, such as presentation timings of the trials.

Analytical Approach

Two separate logistic mixed effects models were constructed in RStudio, version 1.2.5001 (RStudio Team, 2019) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015), to analyze children's accuracy data and examine the extent to which predictors increased or decreased the likelihood (log-odds) of making an accurate response. To examine the separate effects of variability on XSWL performance, accuracy was regressed on two non-orthogonal contrasts using dummy coding. Contrast 1 compared performance in the No Variability Condition (reference condition) to performance in the Multiple Speaker Condition (contrast 1: 0,1,0) and contrast 2 compared performance in the No Variability Condition (reference condition) to the Multiple Exemplar Condition (contrast 2: 0,0,1). The most complex model was fitted following Barr and colleagues (2013) suggested "keep it maximal" approach (Barr, Levy, Scheepers, & Tily, 2013). By-subject and by-item random slopes for contrast 1 and contrast 2 were removed to resolve singularity issues (Brauer & Curtin, 2018). The final model included a by-subject random intercept and a by-item random intercept only.

To examine the combined effects of exemplar and speaker variability on XSWL performance, in a separate model, accuracy was regressed on two different non-orthogonal

contrasts using dummy coding that compared performance in the Combined Variability Condition (reference condition) to performance in the Multiple Speaker Condition (contrast 3: 0,1,0) and Multiple Exemplar Condition (contrast 4: 0,0,1), separately. To resolve singularity issues, by-subject and by-item random slopes for contrasts were removed (Brauer & Curtin, 2018). Akaike and Bayesian Information Criterion scores were used for model selection. The model with the best fit included a by-subject random intercept, a by-subject random slope for contrast 4, and a by-item random intercept. Age, mother's years of education, and non-verbal IQ did not significantly improve model fits ($ps > .05$).

Results

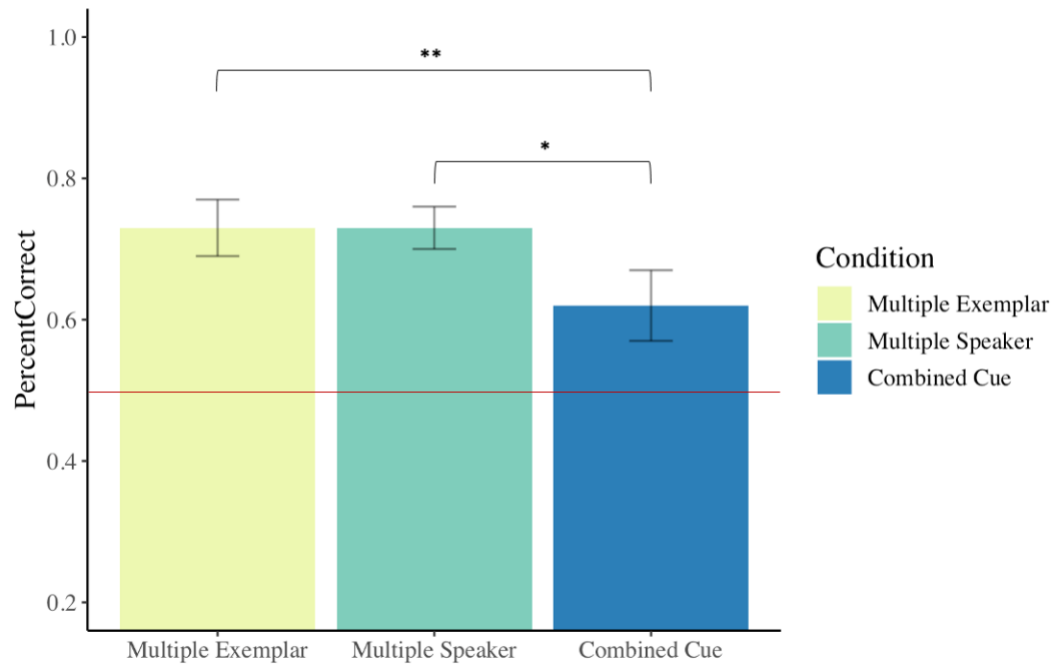
Results revealed that children learned word-object pairs above chance levels (i.e., .50) in all conditions: No Variability Condition ($M = 0.73$, $SD = 0.21$; $t(33) = 6.52$, $p < .001$, $d = 1.12$), Multiple Exemplar Condition ($M = 0.73$, $SD = 0.20$; $t(33) = 6.44$, $p < .001$, $d = 1.10$), Multiple Speaker Condition ($M = 0.73$, $SD = 0.18$; $t(33) = 7.37$, $p < .001$, $d = 1.28$), and Combined Variability Condition ($M = 0.62$, $SD = 0.27$; $t(33) = 2.70$, $p < .05$, $d = 0.46$).

Results from the logistic mixed effects model examining the separate effects of variability on XSWL performance revealed that children demonstrated similar likelihoods of mapping novel words to correct referents in the Multiple Speaker Condition ($B = -0.02$, $SE = 0.19$, $z = -0.10$, $p = 0.92$) and Multiple Exemplar Condition ($B = -0.04$, $SE = 0.25$, $z = -0.16$, $p = 0.88$), compared to the No Variability Condition.

However, model results examining the combined effects of variability on XSWL performance revealed that children were 1.75 times more likely to learn word-object pairs in the Multiple Exemplar Condition than in the Combined Variability Condition ($B = 0.56$, $SE = 0.22$, $z = 2.60$, $p < .01$; *Odds Ratio*: 1.75, *95% CI*: 1.15 - 2.68) (Figure 1). Similarly, children were 1.69

times more likely to learn word-object pairs in the Multiple Speaker Condition than in the Combined Variability Condition ($B = 0.52$, $SE = 0.25$, $z = 2.10$, $p < .05$; *Odds Ratio*: 1.69, 95% *CI*: 1.04 - 2.75) (Figure 1). See Table 3 for full model results. See Table 3 for full model results.

Figure 1. Significant Main Effects of Condition



Note. Error bars denote standard error. Red line depicts chance levels (i.e., .50).

* $p < .05$, ** $p < .01$

Table 3. Full GLMER Results

	Reference Condition: No Variability				Reference Condition: Combined Variability			
	$B (SE)$	z	OR	CI	$B (SE)$	z	OR	CI
Intercept	1.15 (0.22)	5.27***	3.17	2.06 – 4.87	0.58 (0.21)	2.79**	1.79	1.19 – 2.69
Multiple Speaker Condition	-0.02 (0.19)	-0.10	0.98	0.68 – 1.42	0.52 (0.25)	2.10*	1.69	1.04 – 2.75
Multiple Exemplar Condition	-0.04 (0.25)	-0.16	0.96	0.59 – 1.56	0.56 (0.22)	2.60**	1.75	1.15 – 2.68

* $p < .05$, ** $p < .01$, *** $p < .001$

Discussion

In the present study, we examined the separate and combined effects of exemplar and speaker variability on children's XSWL performance. Our results indicate that children encode input variability while learning word-objects associations, suggesting that XSWL is well-suited for the discovery of structure beyond word mappings, such as categorical representations of object categories and speakers' voices. However, while learning was observed across all conditions, variability within a single dimension – in exemplars only and speakers only – did not facilitate or hinder children's statistical word learning. Further, variability in both speakers and exemplars did hinder XSWL performance, suggesting that accommodating multiple forms of variable input may incur costs to statistical word learning in children.

To the best of our knowledge, this is the first study to demonstrate that children can detect and generalize category membership to novel exemplars during XSWL, convergent with findings in adults (e.g., Chen et al., 2017; Chen et al., 2018). However, we did not find evidence in support for our hypothesis that multiple exemplar variability would facilitate XSWL performance. On average, children mapped novel words to their referents similarly in the presence and absence of varying exemplars. This finding contrasts with the large empirical literature showing that exposure to highly variable category members facilitates word learning and generalization (e.g., Ankowski et al., 2013; Gentner et al., 2007; Namy & Genter, 2002; Perry et al., 2010; Twomey et al., 2014). One possibility is that variation in surface level perceptual properties of objects may yield facilitation effects in preschool-aged children (the focus on most prior studies), but not in school-age children (the focus of the present study). Indeed, categorization performance has been shown to improve with age, such that older children are more skilled at utilizing covariations in features and rules to guide learning than younger

children (e.g., Minda et al., 2008; Rabi & Minda, 2014; Visser & Raijmakers, 2012). Therefore, accommodating variations in size, color, and shape across the different exemplars within each category may have been too easy for school-aged children to yield facilitatory effects on learning.

We also failed to find evidence in support of facilitative and interference hypotheses for the effects of speaker variability on children's XSWL. Despite increasing acoustic variability through varying speakers by gender, children learned word-object pairings equally well after being exposed to ten speakers compared to one speaker, in line with previous null findings (Crespo & Kaushanskaya, 2021). It remains an open question why no effect of speaker variability was observed, particularly when facilitatory effects of multiple talker input have been well documented on other word learning tasks (e.g., Apfelbaum & McMurray, 2011; Richtsmeier et al., 2009; Rost & McMurray, 2009; 2010; Höhle et al., 2020; Quam et al., 2017). Perhaps acoustic variability needs to be anchored to the statistical structure of the input to shape, and ultimately boost, learning when learning is measured via a statistical learning task. That was not the case in the present study; speaker identity and gender did not reinforce systematic regularities between words and objects, and thus did not provide informative cues that would help children accrue co-occurring statistics to disambiguate word-referent mappings. However, these findings might also suggest that XSWL may be particularly robust to acoustic variability. An interesting avenue for future research is to examine how children contend with probabilistic versus non-probabilistic cues during XSWL and how cognitive changes that occur during childhood influence the types of cues children prioritize to support their word learning.

While variability within a single dimension (i.e., multiple exemplars or multiple speakers) did not influence learning, results revealed that children were less likely to learn novel

words when presented with variability in two dimensions (i.e., multiple exemplars and speakers). These results are not in line with the central tenets of the variation theory of learning (e.g., Apfelbaum & McMurray, 2011; Gibson & Gibson, 1955; Marton, 2015). One interpretation of these findings is that variability in multiple cues may have placed increased attentional and/or processing demands on disambiguating word-object pairs, hindering word learning during XSWL. Indeed, there are a growing number of studies suggesting that constraints on XSWL may be driven by limitations in attention (Bhat, Spencer, & Samuleson, 2021; Pereira, Smith, & Yu, 2014; Yu, Suanda, & Smith, 2019) and memory capacity (e.g., Bhat et al., 2013; Vlach & DeBrock, 2017; 2019). Future research is needed to elucidate how accommodating variability in object exemplars and speakers interact with domain-general cognitive processes to influence children's XSWL performance. Moreover, an alternative interpretation of these findings, but not a mutually exclusive one, is that XSWL mechanisms may have a limited capacity to flexibly adapt to input characteristics that vary over time. Examining XSWL performance in infant and adult learners under similar variability conditions may provide additional evidence for interpretations that posit maturational or mechanistic constraints on learning.

In conclusion, the current study provides the first empirical evidence that children can generalize word-referent mappings to novel object exemplars via XSWL when trained with multiple exemplars and multiple speakers. The results suggest that XSWL is robust against input variability, while at the same time, sensitive to interference effects associated with variability in multiple dimensions. Together, the results from this work provide new theoretical insights into how fundamental mechanisms of word learning scale to accommodate more complex and naturalistic forms of input.

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Chapter 3: The effects of bilingualism on XSWL performance under different variability conditions

Abstract: Separate literatures have shown that both bilingual language experience and variability in the input impacts children's word learning. These factors are seldom examined together, particularly in the context of statistical learning mechanisms. As a result, it remains unknown how variability in linguistic experiences and variability in the input interact to modulate how children acquire new words. In the present study, we examined the separate and combined effects of exemplar and speaker variability in monolingual and bilingual children's cross-situational word learning (XSWL) performance. Results revealed that children learned word-referent associations equally well when the input varied in a single dimension (i.e., exemplars or speakers) compared to a condition with no variability, independent of their linguistic background. However, when performance in conditions that varied in a single dimension (i.e., exemplars or speakers) was compared to a condition that varied in multiple dimensions (i.e., exemplars and speakers), bilingual word-learning advantages were observed, such that bilinguals were more likely to learn word-referent associations than monolinguals. Together, results suggest that children can learn and generalize word-referent associations from input that varies in exemplars and speakers, and that bilingualism may bolster learning under conditions of increased input variability.

Introduction

Despite high referential ambiguity, children show a remarkable capacity to acquire new words from the linguistic input they receive. One mechanism that has been shown to underlie this capacity is 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). In a traditional XSWL paradigm, learners are exposed to a series of trials that contain multiple words and referents without any information about which word labels each referent. During the exposure phase, words are produced in the presence of their intended referents, as well as other referents, yielding spurious co-occurrences between words and other referents. However, across several ambiguous naming trials, learners aggregate co-occurring statistics and rely on this information to build hypotheses about word-referent pairs. At the end of the exposure phase, word-learning is assessed in a test phase, where participants are instructed to select a referent from several referents for each novel word.

Over the last fifteen years, a growing number of empirical studies (Kachergis, Yu, & Shiffrin, 2012; Smith & Yu, 2008, Suanda, Mugwanya, & Namy, 2014, Vlach & Johnson, 2013; Smith, Smith & Blythe, 2011; Yu & Smith, 2007), computational simulations (e.g., Vong & Lake, 2022), and data from parent-child interactions (Yu, Zhang, Slone, & Smith, 2021; Zhang, Yurovsky, & Yu, 2021), have provided robust evidence for the viability of XSWL. Together, this body of work has significantly contributed to our understanding of how learners resolve the many-to-many mappings between words and referents across the lifespan. However, with a few exceptions (Benitez, Yurovsky, & Smith, 2016; Crespo & Kaushanskaya, 2021; Escudero, Mulak, Fu, & Singh, 2016; Poepsel & Weiss, 2016), research examining XSWL has focused on learning in monolingual English-speaking participants, and on learning words from a single speaker and a single object exemplar. Consequently, it remains unclear how variability in linguistic experiences and variability in the input modulate XSWL performance. Therefore, in the present study, we examined the effects of bilingualism in children's XSWL performance under different variability conditions. Specifically, we examined the effects of speaker variability and exemplar variability in word-learning, separately and combined. We were interested in whether bilingualism would make children especially sensitive to multiple forms of variability in the input. We exposed school-aged children to novel words produced by different speakers and novel object exemplars that differed in their physical attributes (e.g., size, color, and shape) and asked: How might bilingualism influence children's use and generalization of cross-situational statistics?

Bilingualism

The effects of bilingualism on children's word-learning abilities have been almost exclusively examined via fast-mapping paradigms, where word-referent mappings are made

explicit to the learner and are often presented in the absence of competing referents. In such paradigms, bilingual word-learning advantages have been documented in infants (e.g., Singh, Fu, Tay, & Golinkoff, 2017; Singh, 2018), children (Alt, Arizmendi, Gray, Hogan, Green, & Cowan, 2019; Eviatar, Taha, Cohen, & Schwartz, 2018; Yoshida, Tran, Benitez, & Kuwabara, 2011; Kaushanskaya, Gross, & Buac, 2014) and adults (Bogulski, Bice, & Kroll, 2019; Kaushanskaya, 2012; Kaushanskaya & Marian, 2009; Kaushanskaya & Rechtzigel, 2012; Kaushanskaya, Yoo & Van Hecke, 2013; Warmington, Kandru-Pothineni, & Hitch, 2019). For example, Eviatar et al. (2018) exposed Hebrew-Arabic bilingual children and monolingual Hebrew and Arabic-speaking children to pictures of unfamiliar objects and pseudowords. At test, bilingual children identified more novel pictures and produced novel words more accurately than monolingual children. Bilingual word-learning advantages have also been observed in school-aged children with classroom exposure to a second language (Kaushanskaya et al., 2014), suggesting that even limited amounts of bilingual exposure can engender effects on word-learning abilities. Bilingual word-learning advantages may stem from enhancements in phonological working memory (Eviatar et al., 2018; Kaushanskaya, 2012), and executive function skills, like inhibition – the ability to control attention and inhibit task-irrelevant information (e.g., Darcy, Mora & Daidone, 2016; Warmington et al., 2019; Yoshida et al., 2011).

However, some researchers have failed to find reliable word-learning differences between monolinguals and bilinguals (e.g., Alt et al., 2019; Alt, Meyers, & Figueroa, 2013; Buac, Gross, & Kaushanskaya, 2016; de Diego-Lázaro, Pittman, & Restrepo, 2021). In a recent study, Alt et al., (2019) found no group differences in word-learning accuracy on six tasks that required monolingual and bilingual children ages 7 – 9 to learn names of novel sea monsters. Similarly, Buac et al. (2016) reported that monolingual and bilingual children were equally

accurate at mapping novel words to familiar referents and unfamiliar referents (i.e., aliens). Taken together, it remains uncertain whether bilingualism confers word-learning advantages. In the present study, we examined if bilingualism impacts XSWL performance. Compared to fast-mapping paradigms, XSWL may be a more challenging learning task, one that may be more sensitive to differences in linguistic experiences.

The extant literature does not provide a clear answer to the question of whether bilingualism broadly modulates statistical learning abilities. Varying patterns of findings have been documented across different age ranges, bilingual proficiency profiles, types of statistical dependencies (i.e., transitional probabilities, grammar rules, co-occurring regularities), and number of patterns to be learned (for a review see Weiss, Schwob, & Lebkuecher, 2020). Despite the mixed findings, there is mounting evidence that bilingualism may promote the development of more flexible and efficient statistical learning abilities, in line with the structural sensitivity theory (Kuo & Anderson, 2010, 2012). The structural sensitivity theory posits that bilinguals may be more adept at detecting new patterns in the input. This superior sensitivity to structure is theorized to stem from a bilingual's habitual experience of detecting the parameters that separate their two languages. Indeed, bilingual statistical learning advantages have been documented most consistently in paradigms that require the detection of multiple speech and rule structures (e.g., Antovich & Graf Estes, 2018; Kovács & Mehler, 2009; Onnis, Chun & Lou-Magnuson, 2018; Wang & Saffran, 2014), as well as novel phonological patterns (Kuo & Anderson, 2012). For instance, Kuo and Anderson (2012) exposed monolingual and bilingual school-aged children to novel phonotactic regularities in an artificial language. Results revealed that bilingual children acquired the statistical regularities for sound patterns more efficiently than monolingual children.

In the present study, we asked whether bilingual language experience may also yield facilitative effects on XSWL performance.

To date, only four studies – three in adults and one in children – have examined the effects of bilingualism on XSWL performance, and the results have been markedly mixed. Escudero et al., (2016) found that compared to monolingual adults, bilingual adults were more accurate at mapping objects to novel words that had different sounds patterns (i.e., bon vs. deet) as well as for novel words that varied by only one sound (e.g., bon vs. pon; dit vs. dut). Conversely, Poepsel and Weiss (2016) found that monolinguals, English-Spanish bilinguals, and Mandarin-English bilinguals learned one-to-one word-referent mappings equally well. However, bilingual adults outperformed monolingual adults when learning required mapping two words to one referent. In contrast, Benitez et al., (2016) reported no group differences between monolingual and multilingual adults when learning required mapping one word or two words, to one referent. However, bilinguals successfully learned two words with distinct phonotactic structures for one referent, whereas monolinguals only mapped one of two words with different phonotactic structures to its intended referent.

In children, Crespo and Kaushanskaya (2021) found that monolingual children were faster and more accurate at learning word-referent mappings during XSWL than bilingual children. In this study, monolingual children were from higher socioeconomic status homes, a factor associated with word learning abilities (e.g., Hoff, 2013; Fernald, Marchman, & Weisleder 2013). Although controlling for socioeconomic status did not mitigate word-learning differences between groups, it is possible that poorer word-learning in bilinguals could have been driven, at least in part, by lower socioeconomic status. In the present study, we compared XSWL performance in a group of demographically matched monolingual and bilingual children. We

hypothesized that if bilingual language experience broadly enhances XSWL abilities, then bilingual children will show more robust word-learning than monolingual children, in line with Escudero et al. (2016). However, if XSWL is not broadly influenced by bilingual language experience, then bilingual and monolingual children will perform equally well, consistent with previous findings in adults (Benitez et al., 2016; Poepsel & Weiss, 2016). In addition to testing whether bilingualism broadly influenced children's word-learning, we were interested in examining whether bilingual language experience would influence how learners accommodated variability in exemplars and speakers in XSWL.

Input Variability

Studies have shown that children (Crespo & Kaushanskaya, 2021; Suanda et al., 2014; Zettersten, Wojcik, Beneitez, & Saffran, 2018) and adults (Dautriche & Chemla, 2014; Kachergis, Yu, Shiffrin, 2009) are sensitive to variability effects during XSWL. With regard to exemplar variability, recent research has shown that monolingual adults (Chen, Gershkoff-Stowe, Yu, Cheung, & Yu, 2017; Chen, Zhang, & Yu, 2018; Gangwani, Kachergis, & Yu, 2010) can infer category membership when exposed to multiple exemplars via cross-situational statistics. However, it remains unclear whether exemplar variability bolsters XSWL performance. A large number of empirical studies demonstrate that exemplar variability supports children's explicit word-learning, category learning, and generalization (e.g., Ankowski, Vlach, & Sandhofer, 2013; Gentner, Loewenstein, & Hung, 2007; Namy & Genter, 2002; Perry, Samuelson, Malloy, & Shiffer, 2010; Twomey, Ranson, & Horst, 2014). Therefore, we hypothesized that if facilitative effects of exemplar variability observed in explicit learning paradigms extend to XSWL, then children will learn more word-referent pairs when exposed to multiple exemplars than one exemplar. Alternatively, statistical learning mechanisms may be

insensitive to exemplar variability. In this instance, children may learn novel words similarly when exposed to one exemplar and multiple exemplars. Another potential outcome is that mapping novel words to objects that perceptually differ from trial to trial, but belong to the same category, may heighten the uncertainty of word-referent mappings. If true, exposure to multiple exemplars may impact XSWL performance in monolinguals and bilinguals differently.

Bilingualism has been shown to promote the development of different, and in some cases more flexible, word-mapping strategies (e.g., Brojde, Ahmed, & Colunga, 2012; Byers-Heinlein & Werker, 2009; Colunga & Smith, 2005). For example, monolingual children more strictly adhere to the one-object-one-name rule than bilingual children (i.e., mutual exclusivity, Markman, 1991) (e.g., Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Byers-Heinlein & Werker, 2009; Houston-Price, Caloghiris & Raviglione, 2010). Monolingual children have also been shown to depend more on common perceptual features, like shape, to categorize objects (e.g., Brojde et al., 2012) whereas bilingual children capitalize more on social-pragmatic cues, like eye gaze (e.g., Brojde et al., 2012; Gangopadhyay & Kaushanskaya, 2020; Yow & Markman, 2011). Bilingual children are also more skilled than monolingual children at sorting items by multiple dimensions (e.g., Bialystok, 1999; Bialystok & Martin, 2004), a cognitive skill that may be especially useful in accommodating multiple exemplars. Therefore, we hypothesized that bilinguals may be especially adroit at accommodating multiple exemplars during XSWL, compared to monolinguals. Alternatively, multiple exemplars may impact XSWL performance in monolinguals and bilinguals to the same degree, or not at all. In addition to the effects of exemplar variability, we were also interested in the effects of speaker variability on children's XSWL performance.

Speaker variability has been shown to support children's word-learning (e.g., Apfelbaum & McMurray, 2011; Richtsmeier, Gerken, Goffman, & Hogan, 2009; Rost & McMurray, 2009; 2010; Höhle, Fritzsche, Meß, Phillip, & Gafos, 2020; Quam, Knight, & Gerken, 2017) and generalization (e.g., Rost, McMurray, 2009; 2010). Facilitative effects of speaker variability have been grounded in the early learning theory, which posits that variability of irrelevant cues helps attune focus to useful cues (e.g., Apfelbaum & McMurray, 2011). However, in the speech processing literature, speaker variability is associated with processing costs, such that participants, particularly children (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997), tend to display lower accuracy and/or slower response time on word recognition tasks when exposed to multiple talker input (e.g., Kishon-Rabin et al., 2009; Bressler, Masud, Bharadwaj, & Shinn-Cunningham, 2014; Choi & Perrachione, 2019; Lim, Shinn-Cunningham, & Perrachione, 2019; Magnuson & Nusbaum, 2007). Some researchers theorize that processing costs associated with speaker variability may reflect cognitive costs involved in switching attention from one auditory source to another (Choi & Perrachione, 2019; Kapadia & Perrachione, 2020). Given evidence that bilingualism may enhance talker-voice processing abilities and influence the neural mechanisms of auditory selective attention (e.g., Fecher & Johnson, 2019; 2022; Levi, 2018; Olguin, Cekic, Bekinschtein, Katsos, & Bozic, 2019), it is reasonable to hypothesize that bilingual language experience may facilitate learning from multiple speaker input. Yet, recent research has failed to find evidence for facilitative and interference effects of speaker variability as well as for bilingual advantages in accommodating speaker variability during XSWL (Crespo & Kaushanskaya, 2021).

In the present study, we included male speakers in addition to female speakers to create more acoustic variability than in Crespo & Kaushanskaya (2021), to strengthen the effect of

speaker variability, if such an effect exists. We hypothesized that if speaker variability negatively impacts children's XSWL performance, then bilingual children would outperform monolingual children in mapping word-referent pairings from multiple speaker input. However, if speaker variability positively impacts children's XSWL performance, then bilingual and monolingual children will likely equally benefit. We also considered the possibility that speaker variability would yield a null effect, in line with Crespo & Kaushanskaya (2021) – and in that case, we would also expect monolingual and bilingual children to show similar levels of word-referent mapping from multiple speaker input.

A critical question for the present study was whether bilingual children, compared to monolingual children, would be particularly adept at accommodating simultaneous exemplar-speaker variability during XSWL. Variability in multiple dimensions (i.e., exemplars and speakers) may place increased attentional, and/or processing demands on learning, compounding the difficulty of disambiguating word-object mappings. This manipulation may interfere with XSWL, particularly for monolingual children, whose performance on other statistical learning paradigms has been shown to be impaired when learning required accommodating more complex input (e.g., Antovich & Graf Estes, 2018; Kovács & Mehler, 2009). On the other hand, separate literatures suggest that bilingualism may enhance statistical learning abilities under conditions of increased complexity (e.g., Antovich & Graf Estes, 2018; Kuo & Anderson, 2012; Kovács & Mehler, 2009) as well as the development of attention control (e.g., Darcy et al., 2016; Warmington et al., 2019; Yoshida et al., 2011) and word-learning skills (e.g., Alt et al., 2019; Eviatar et al., 2018; Yoshida et al., 2011; Kaushanskaya et al., 2014). Therefore, we hypothesized that bilingual children would demonstrate superior XSWL performance compared

to monolingual children when multiple exemplars and speakers are combined and presented simultaneously in the input.

Methods

Participants

This study was reviewed and approved by the Education and Social/Behavioral Science Institutional Review Board at the University of Wisconsin-Madison. All data collection was conducted remotely via Zoom.

Seventy-seven children ages 5 – 8 were recruited. Two monolingual and two bilingual participants were excluded because they could not engage via Zoom. One monolingual and one bilingual participant were also excluded because they failed to complete a second session to finish study tasks. The final sample included 34 English monolinguals ($M_{\text{age}} = 6.87$; 14 boys) and 37 Spanish-English bilinguals ($M_{\text{age}} = 7.26$; 16 boys). Exclusionary criteria consisted of 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). Monolingual children acquired English from birth and reported less than 5% consistent exposure to other languages at any time. On average, bilingual children were first exposed to English and Spanish by twelve months of age. At the time of testing, on average, bilingual children were exposed to English 59.27% and Spanish 40.73% during their waking hours. Mother's years of education was used as proxy for SES and was collected through the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). See Table 1 for participant characteristics.

Table 1. Participant Characteristics

	Monolinguals	Range	Bilinguals	Range	<i>t</i>
N	34 (14 boys)		37 (16 boys)		
Age	6.86 (1.07)	5.08 – 8.83	7.26 (1.09)	5.17 – 8.83	1.56
Mother's Years of Education	16.96 (1.97)	13 – 22	16.55 (3.53)	8 – 24	-0.60
Nonverbal IQ ^a	111.97 (16.23)	74 – 144	114.00 (13.11)	72 – 133	0.58
First Exposure to English (months)	0.00 (0.00)	0 – 0	12.05 (18.35)	0 – 54	4.00***
Current English Exposure (%)	99.32 (1.49)	95 – 100	59.27 (17.59)	15 – 90	- 3.80***
English Language Skills ^b	108.18 (13.93)	81 – 141	101.91 (13.73)	75 – 122	-1.88
First Exposure to Spanish (months)	-	-	1.97 (08.17)	0 – 48	-
Current Spanish Exposure (%)	0.68 (1.49)	0 – 5	40.73 (17.59)	10 – 85	-
Spanish Language Skills ^c	-	-	100.87 (13.32)	-	-
<hr/> n <hr/>					
<u>Child's Dominant Language</u>					
English			22		
Spanish	-		3		
English & Spanish equally			12		
<hr/> <u>Language Mostly Spoken at</u>					
<u>Home</u>					
English	-		15		
Spanish			10		
English & Spanish equally					

^a Visual Matrices subtest, Kauffman Brief Intelligence Test – 2nd Edition

^b Core Language Index Score from Clinical Evaluation of Language Fundamentals – 5th Edition (CELF-5)

^c Core Language Index Score from Clinical Evaluation of Language Fundamentals – 4th Edition, Spanish (CELF-4 Spanish)

** $p < .01$, *** $p < .001$

Experimental Task

Each child completed a XSWL task in four experimental conditions in a within-subject design on Gorilla (<https://gorilla.sc>), an online platform for building and hosting experiments online. Children completed two word learning conditions per session. Condition order was counterbalanced across participants.

Stimuli. Four lists of 5 novel words were retrieved from the Gupta et al. (2004) database. Novel words were English-like and matched on English and Spanish biphone probability and neighborhood density (calculated from the online CLEARPOND Database) across lists. Each novel word was paired with a novel object selected from the Horst & Hout (2016) Novel Object & Unusual Name (NOUN) Database 2nd Edition, which contains colorful novel objects normed on familiarity and name-ability scores. Word-object pairs were counter-balanced across condition. See Appendix A for the lists of word-object pairings by order and condition.

Exemplars. Each category contained three novel object exemplars provided by the NOUN Database (Horst & Hout, 2016) that varied in their physical attributes (i.e., size, color, shape). One additional exemplar was created in PowerPoint by altering the image color. In each category, three object exemplars were randomly assigned to serve as exposure items and one as a test item.

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 2 for average frequency and duration characteristics for each speaker.

Table 2. Average Frequency and Duration Characteristics for Speakers by Condition

	Fundamental Frequency (F0, Hz)	Minimum Pitch (Hz)	Maximum Pitch (Hz)	Word Duration (seconds)
Single Speaker & Multiple Exemplar				
Female Speaker 1	256.90	158.66	278.09	0.97
Female Speaker 2	218.70	166.61	271.62	1.07
Multiple Speaker & Combined Cue				
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

Conditions. The four experimental conditions were: 1. No Variability Condition, where children were exposed to one exemplar labeled by one female speaker; 2. Multiple Exemplar Condition, where children were exposed to three exemplars of each category labeled by one female speaker; 3. Multiple Speakers Condition, where children were exposed to one exemplar labeled by 5 male and 5 female speakers. In this condition, each production of a word was labeled by a different speaker; and 4. Combined 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 also labeled by a different speaker. Children were exposed to different speakers and objects in each condition and condition order was counterbalanced across participants.

Procedure. The XSWL task consisted of an exposure phase and a test phase. In the exposure phase, children were instructed to look, listen, and learn the names of new toys (i.e., novel objects). Critically, no information about which novel word labeled which object was provided during the exposure phase. Each word-object pair was presented ten times in a pseudorandomized order across a total of 25 trials, appearing with every other word-object pair. At trial onset (i.e., 0 ms), two novel objects were displayed right-centered and left-centered, and the first novel word was produced. The second novel word was produced 2000 ms after trial onset and the next trial appeared after approximately 6000 ms.

The testing phase followed immediately after the exposure phase. 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. In each test trial, novel objects were displayed at trial onset and the target word was produced at 2000ms. Response buttons appeared around the novel objects and participants had 4000ms to select a novel object. All test

objects were novel exemplars, and all target words were produced by a different female speaker not heard during any of the exposure phases. See Appendix B for a list of example exposure trials and test trials in each condition.

Analytical Approach

Two separate logistic mixed effects models were constructed in RStudio, version 1.2.5001 (RStudio Team, 2019) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) to examine the extent to which predictors increased or decreased children's likelihood (log-odds) of making an accurate response. In both models, accuracy data was regressed on Language Group (contrast coded; monolingual vs. bilingual) and Condition (non-orthogonal contrasts using dummy coding). To examine the effects of variability on XSWL performance, in Model 1, performance in the No Variability Condition (reference condition) was compared to performance in the Multiple Speaker Condition (contrast 1: 0,1,0), and the Multiple Exemplar Condition (contrast 2: 0,0,1). The addition of English age of acquisition ($\chi^2(1) = 2.27, p = 0.13$) and current English language exposure ($\chi^2(1) = 2.43, p = 0.12$) did not significantly improve model fit and therefore were not included as covariates.

To examine the combined effects of exemplar and speaker variability on XSWL performance, in Model 2, the Combined Variability Condition served as the reference condition, and was compared to performance in the Multiple Speaker Condition (contrast 3: 0,1,0) and Multiple Exemplar Condition (contrast 4: 0,0,1). The addition of English age of acquisition ($\chi^2(1) = 8.27, p < .01$), but not current English language exposure ($\chi^2(1) = 1.53, p = 0.22$), significantly improved model fit and was included as a covariate in Model 2. Model 1 and Model 2 were each fitted with the maximum random effect structure (Barr, Levy, Scheepers, & Tily, 2013). However, by-item random slopes for contrasts and Language Group were removed to

resolve singularity and convergence issues (Brauer & Curtin, 2018). Final models included by-subject random intercepts, by-subject random slopes for each contrast, and by-item random intercepts. The addition of age, mother's years of education, and non-verbal IQ did not significantly improve fit for neither model ($ps > .05$).

Results

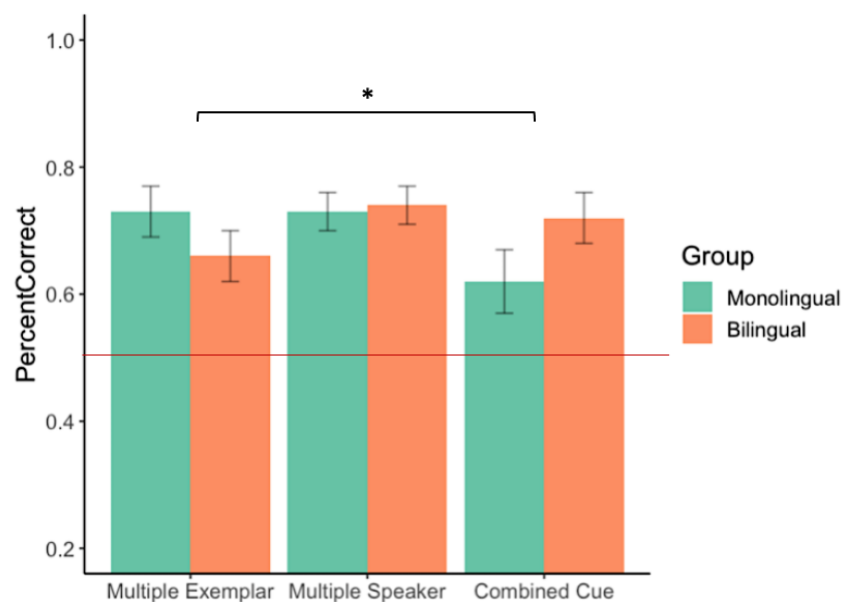
Results revealed that children learned word-object pairs above chance levels (i.e., .50) in the No Variability Condition ($M = 0.74$, $SD = 0.21$; $Range: 0.20 - 1.00$; $t(70) = 9.45$, $p < .001$, $d = 1.12$), Multiple Exemplar Condition ($M = 0.69$, $SD = 0.23$; $Range: 0.20 - 1.00$; $t(70) = 6.91$, $p < .001$, $d = 0.82$), Multiple Speaker Condition ($M = 0.74$, $SD = 0.18$; $Range: 0.30 - 1.00$; $t(69) = 10.71$, $p < .001$, $d = 1.28$), and Combined Variability Condition ($M = 0.67$, $SD = 0.26$; $Range: 0.10 - 1.00$; $t(70) = 5.69$, $p < .001$, $d = 0.68$).

Logistic mixed effects model results examining the separate effects of variability on XSWL performance revealed that monolingual and bilingual children demonstrated similar likelihoods of mapping novel words to correct referents ($B = 0.17$, $SE = 0.30$, $z = 0.55$, $p = 0.58$). Additionally, word-learning performance in the Multiple Speaker Condition ($B = -0.20$, $SE = 0.19$, $z = -1.04$, $p = 0.30$), and the Multiple Exemplar Condition ($B = -0.30$, $SE = 0.23$, $z = -1.32$, $p = 0.19$) was not significantly different than word-learning performance in the No Variability Condition. All other effects were not significant.

Model results examining the combined effects of variability on XSWL performance revealed a significant main effect of Language Group such that, overall, bilingual children were 2.40 times more likely to learn word-object pairs than monolingual children when variability was present in the input ($B = 0.88$, $SE = 0.35$, $z = 2.47$, $p < .05$; $Odds Ratio: 2.40$, $95\% CI: 1.20 - 4.81$). This model also revealed a significant interaction between Language Group and Contrast

4, which compared word learning performance in the Multiple Exemplar Condition to the Combined Cue condition ($B = -0.95$, $SE = 0.38$, $z = -2.47$, $p < .05$; *Odds Ratio*: 0.39, 95% *CI*: 0.18 - 0.82) (Figure 1). See Table 3 for full model results of the main analyses.

Figure 1. Condition by Language Group Interaction



Note. Error bars denote standard error. Red line depicts chance levels (i.e., .50).

* $p < .05$

Table 3. Full GLMER Results for the Main Analyses

	Reference Condition: No Variability				Reference Condition: Combined Variability			
	B (SE)	z	OR	CI	B (SE)	z	OR	CI
Intercept	1.15 (0.22)	5.27***	3.17	2.06 – 4.87	0.58 (0.21)	2.79**	1.79	1.19 – 2.69
Multiple Speaker Condition	-0.02 (0.19)	-0.10	0.98	0.68 – 1.42	0.52 (0.25)	2.10*	1.69	1.04 – 2.75
Multiple Exemplar Condition	-0.04 (0.25)	-0.16	0.96	0.59 – 1.56	0.56 (0.22)	2.60**	1.75	1.15 – 2.68

* $p < .05$, ** $p < .01$, *** $p < .001$

To interpret the significant interaction, the simple effects of Language Group was tested at each level of Condition via a logistic regression model using the glm (generalized linear model) function, covarying for English age of acquisition. Language Group membership significantly predicted children’s word-learning accuracy in the Combined Cue Condition ($B = 0.90$, $SE = 0.38$, $z = 2.39$, $p < .05$; *Odds Ratio*: 2.46, 95% *CI*: 1.17 – 5.13), such that bilinguals were 2.46 times more likely to select the correct word-object pair at test. Language Group membership did not significantly predict word learning performance in the Multiple Exemplar Condition ($z = 0.17$, $p = .87$).

Additionally, model results revealed a significant main effect of English age of acquisition such that for a one unit decrease in English age of acquisition, the odds of correctly mapping a word-object pair significantly increased by a factor of 0.98 ($B = - 0.22$, $SE = 0.008$, $z = - 2.93$, $p < .01$; *Odds Ratio*: 0.98, 95% *CI*: 0.96 – 0.99). Table 4 for full model results of the simple effects analyses.

Table 4. Full GLMER Results for the Simple Effects Analyses

Conditions:	Model 1 ^a				Model 2 ^b			
	Multiple Exemplar				Combined Cue			
	B (SE)	z	Odds Ratio	95% CI	B (SE)	z	Odds Ratio	95% CI
Intercept	1.11 (0.49)	2.24*	3.03	1.15 – 7.98	- 0.24 (0.56)	- 0.44	0.78	0.26 – 2.33
Language Group	0.05 (0.32)	0.17	1.05	0.56 – 1.97	0.90 (0.38)	2.39*	2.46	1.17 – 5.13
English Age of Acquisition	- 0.03 (0.01)	- 2.94**	0.97	0.95 – 0.99	- 0.03 (0.01)	- 2.01*	0.97	0.95 – 1.00

^a By-item random slope for Language Group was removed to resolve singularity issues

^b By-item random intercept and by-item random slope for Language Group was removed to resolve singularity and convergence issues

* $p < .05$, ** $p < .01$, *** $p < .001$

Discussion

In the present study, we examined the effect of bilingualism on children's XSWL performance under different variability conditions. When performance in conditions that varied in a single dimension (i.e., exemplars or speakers) were compared to learning in a condition that varied in multiple dimensions (i.e., exemplars and speakers), bilingual word-learning advantages were observed, such that overall, bilinguals were more likely to learn word-referent associations than monolinguals. Bilinguals were especially better than monolinguals at accommodating simultaneous exemplar-speaker variability during XSWL. In contrast, children learned word-referent associations equally well when the input varied in a single dimension (i.e., exemplars or speakers) compared to a condition with no variability, irrespective of their linguistic background. Together, results from the current study suggest that bilingualism may bolster learning under conditions of increased input variability.

We failed to find evidence in support for the hypothesis that bilingualism broadly enhances XSWL performance, as observed in adults in Escudero et al. (2016). In the present study, bilingual children were no more adept than monolingual children at learning word-referent mappings when performance in the multiple exemplar and multiple speaker conditions were compared to the no variability condition. The results are consistent with the small number of studies suggesting that bilingualism may not modulate core XSWL abilities (i.e., one-to-one word-referent mappings) (e.g., Beneitez et al., 2016; Poepsel & Weiss, 2016). Our results contribute to this growing literature and indicate that bilingual language experience may not influence how children map one-to-one word-referent pairs, infer category membership from multiple exemplar exposure, or accommodate to multiple speaker input, during XSWL.

In line with prior research, our findings suggest that bilingualism may influence XSWL performance under complex learning conditions (e.g., Benitez et al., 2016; Poepfel & Weiss, 2016). This finding also parallels findings in the broader statistical learning literature, where bilingual advantages are most consistently observed under conditions of increased complexity, such as when tracking statistics for multiple structures, multiple competing cues, or remapping words (e.g., Antovich & Graf Estes, 2018; Benitez et al., 2016; Kovács & Mehler, 2009; Onnis et al., 2017; Poepfel & Weiss, 2016; Wang & Saffran 2014). The current study extends this body of work and suggests that bilingualism may also facilitate the detection of word-referent associations in the presence of multiple exemplar and multiple speaker input, especially when the cues are combined.

It remains an open question why bilingual language experience facilitated learning in the current study. Accommodating input variability during XSWL, particularly in multiple dimensions, may have loaded more heavily on processes that are enhanced in bilinguals, such as working memory (Eviatar et al., 2018; Kaushanaskaya & Marian, 2009), and/or inhibition (e.g., Darcy et al., 2016; Warmington et al., 2019; Yoshida et al., 2011), allowing bilinguals to detect word-referent associations more efficiently than monolinguals. Another possibility, but not a mutually exclusive one, is that bilinguals' enhanced awareness of linguistic structure allowed them to detect and reorient attention to word forms – in line with the structural sensitivity theory (Kuo & Anderson, 2012). Indeed, it's likely that enhancements in the abilities to detect (e.g., Kuo & Anderson, 2012), inhibit (e.g., Yoshida et al., 2011), and process (e.g., Eviatar et al., 2018) informative vs. non-informative cues supported bilingual children's word-learning when the input varied along multiple dimensions. Future research is needed to elucidate how different

variability manipulations interact with domain-general cognitive processes to influence children's XSWL performance.

Beyond the variability in linguistic experience, this study was designed to test the effect of variability in the input on XSWL performance. We failed to find evidence in support for facilitative and interference hypotheses of exemplar variability. In the present study, children mapped word-referent pairings similarly when exposed to a single object exemplar and multiple object exemplars. These results suggest that, like adults (e.g., Chen et al., 2017), children can successfully generalize category membership to novel exemplars during XSWL. Our findings also suggest that XSWL may be insensitive to exemplar variability effects, at least as manipulated here. One possibility is that facilitative effects of multiple exemplar exposure observed in the explicit word-learning literature (e.g., Ankowski et al., 2013; Gentner et al., 2007; Namy & Genter, 2002; Perry et al., 2010; Twomey et al., 2014) may not extend to statistical learning paradigms. However, facilitative effects of exemplar variability were plausible given recent evidence showing that school-aged children ages 7 – 9 are sensitive to feature regularities that define visual objects (Broedelet, Boersma, & Rispens, 2022). In this study, Broedelet and colleagues (2022) showed that children rely on the distribution of such regularities to build novel object categories (Broedelet et al., 2022). Therefore, null effects of exemplar variability in the current study may have been a product of our specific variability manipulation. Accommodating co-variations in low-level perceptual features (i.e., size, color, and shape) to categorize novel exemplars may have been too easy for school-aged children to yield facilitatory effects on learning, and possibly, bilingual advantages. Perhaps if categories were indexed by higher-order regularities between words and perceptual features, like in adult

studies (i.e., Chen et al., 2017), an effect of exemplar variability, and/or an interaction between exemplar variability and bilingualism, may have emerged.

We also failed to find evidence in support for facilitative and interference hypotheses of speaker variability. Children mapped word-referent pairs, and generalized production of novel words to a novel speaker, equally well when exposed to one speaker and ten different speakers. Crespo and Kaushanskaya (2021) observed a similar null finding of speaker variability, suggesting that the process of disambiguating word-referent mappings may not be sensitive to fluctuations in speech sound productions. One consideration is that novel word learning was measured receptively. Perhaps facilitative (or interference) effects of speaker variability would have been observed if children were required to produce novel words learned at test (e.g., Richtsmeier et al., 2009). Another consideration is that all novel words were English-like, and all speakers and most children were native English-speakers. Disambiguating word-referent mappings, and adaptations to the test talker, may have been more sensitive to speaker variability effects if the manipulation employed non-native accented speakers (e.g., Bradlow & Bent, 2008; Bent & Holt, 2013), and/or non-English novel words (e.g., Wiener & Lee, 2020). These manipulations would also lend themselves nicely to explore whether bilingualism may enhance XSWL under different acoustic conditions. Indeed, there are several open questions left to explore that would advance our understanding of how variability in the input, and variability in linguistic experiences, interact to modulate word-learning performance across development.

In conclusion, the current study demonstrated that monolingual and bilingual children can generalize word-referent regularities via XSWL when trained with multiple exemplars and multiple speakers. Variability in a single dimension (i.e., exemplars or speakers) and variability in multiple dimensions (i.e., exemplars and speakers) did not broadly impact XSWL

performance. However, compared to monolingual children, bilingual children were more likely to learn word-referent when variability was present in the input, particularly when the input varied in multiple dimensions (i.e., exemplars and speakers). Together, the results from this work provide new theoretical insights into how variability in linguistic experiences and variability in the input interact and influence a fundamental mechanism underlying word learning. The pattern of results in the current study also highlights the importance of comparing demographically matched monolingual and bilingual children. By doing so, we further our understanding about whether, and under what conditions, bilingualism uniquely contributes to individual differences in word learning performance, over and above other factors associated with diverse linguistic experiences.

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Chapter 4: The graded effects of bilingualism and language ability on children's XSWL performance under low and high variability conditions

Abstract: Research has shown that children can discover relationships between words and meanings in ambiguous scenarios by aggregating co-occurring statistics over time – a process termed cross-situational word learning (XSWL). It remains unknown how variability in the learner, and variability in the input, interact and influence XSWL performance. In the present study, we examined the effects of bilingualism on XSWL in a group of school-aged children with a wide range of language abilities. We were interested in whether length of bilingual experience and/or language ability would contribute to XSWL performance under low and high variability conditions. Results revealed graded effects of bilingualism and language ability on XSWL performance under conditions of increased variability. In a high variability condition, where children were exposed to multiple exemplars and speakers simultaneously, word-learning performance significantly decreased as children's length of bilingual experience and language skills decreased. Input variability did not influence word-learning performance for children with greater levels of bilingual experience; children learned word-referent mappings equally well in the presence and absence of input variability. However, for children with higher levels of language ability, input variability improved word-learning performance. Together, the results suggest that variation in the learner and variation in the input interact and modulate mechanisms of lexical learning in children.

Introduction

Cross-situational word learning (XSWL) – the ability to learn word-referent mappings by aggregating co-occurring statistics between words and referents over time (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, Yurovsky, & Smith, 2016; Escudero, Mulak, Fu, & Singh, 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 role of bilingual experience in XSWL performance.

We were especially interested in whether different levels of bilingual experience would yield distinct consequences for XSWL under increased input variability. We administered a

XSWL task under low and high variability conditions to a group of Spanish-English bilingual school-aged children with a wide range of second language acquisition histories. In the low variability condition, children were exposed to one speaker and one exemplar for each object – the traditional XSWL experimental design. In the high variability condition, children were exposed to different speakers and novel object exemplars that differed in their physical attributes (e.g., size, color, and shape).

Bilingualism

There is a relatively small number of studies examining the effects of bilingualism on XSWL performance (Benitez et al., 2016; Crespo & Kaushanskaya, 2021; Escudero et al., 2016; Poepsel & Weiss, 2016). The pattern of results generally suggest 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 observed under conditions of increased complexity (Benitez et al., 2016; Poepsel & Weiss, 2016). Complexity in bilingual XSWL research has primarily been manipulated through increasing the number of words mapped to one referent (Benitez et al., 2016; Poepsel & Weiss, 2016) and/or through increasing the phonological complexity of the novel words (e.g., Benitez et al., 2016; Escudero et al., 2016).

In contrast, complexity in the form of variable input has received little to no attention in the XSWL literature. Variability in speakers and exemplars may have consequences for XSWL given the inconsistencies in the signal: productions of words vary from speaker to speaker and perceptual properties vary across exemplars. To date, only one study has examined the effects of speaker variability and bilingualism jointly on XSWL performance (Crespo & Kaushanskaya,

2021). Results revealed monolingual XSWL advantages, such that monolingual children were faster and more accurate at learning word-referent pairs than bilingual children. The authors also found that speaker variability did not facilitate nor hinder children's XSWL performance. In the present study, we increased the variability in the input by simultaneously varying exemplars in addition to speakers. While overall effects of bilingualism on XSWL were possible, the crucial question was whether the length of bilingual experience influenced XSWL under increased input variability.

Researchers have theorized that bilingual XSWL advantages may reflect bilingual enhancements in cognition (e.g., Benitez et al., 2016; Escudero et al., 2016; Poepsel & Weiss, 2016). Indeed, there is some evidence to suggest that bilingualism may boost the development of phonetic learning skills (e.g., Antoniou, Liang, Ettliger, & Wong, 2015; Bialystok, Majumder, Martin, 2003), word learning skills (e.g., Alt, Arizmendi, Gray, Hogan, Green, & Cowan, 2019; Eviatar, Taha, Cohen, & Schwartz, 2018; Kaushanskaya, Gross, & Buac, 2014) as well as executive function processes, like attention control (e.g., Bialystok & Martin, 2004; Carlson & Meltzoff, 2008; Kapa & Colombo, 2013), inhibition (e.g., Bialystok & Martin, 2004; Bialystok & Viswanathan, 2009) and switching (e.g., Bialystok & Martin, 2004; Martin-Rhee & Bialystok, 2008). However, the notion of bilingual advantages is heavily contested within the bilingual literature. Some researchers have pointed out that 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; Kaushanskaya & Prior, 2015; Kremin & Byers-Heinlein, 2021; Marian & Hayakawa, 2021; Takahesu Tabori, Mech, &

Atagi, 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 executive function skills, like attention (e.g., Adesope, Lavin, Thompson, & Ungerleider, 2010; Barac, Moreno, & Bialystok, 2016; Bialystok, 2011; Bialystok, Craik, Green, & Gollan, 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, Toplak, & Bialystok, 2017; Chung-Fat-Yim, Sorge, & Bialystok, 2020). For example, Sorge and colleagues (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. We posit similar graded effects of bilingualism on XSWL under increased input variability. Specifically, we hypothesized that if effects of bilingualism on XSWL are specific to conditions of increased complexity, then XSWL performance in the high variability condition will increase with increases in length of bilingual experience. Alternatively, exposure to variable input may not impact XSWL performance at all. In this case, children would perform similarly in low and high variability conditions independent of their bilingual experience.

In addition to examining fluctuations in bilingual experience, we considered whether fluctuations in language ability moderated 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 vary 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, Pearson, & Cobo-Lewis, 2007). Many typically developing bilingual children in the early stages of language acquisition experience difficulties 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, Rice, Crago, & Marquis, 2008). At the same time, as reviewed above, bilingual children display enhancements in other linguistic and cognitive skills (e.g., word-learning abilities, attention). Therefore, examining both constructs allowed us to determine which aspects of experience and ability contribute to individual differences in XSWL performance in linguistically diverse learners.

Language Ability

Individual differences in language ability are linked to individual differences in XSWL performance (e.g., Hartley, Bird, & Monaghan, 2020; McGregor, Smolak, Jones, Oleson, Eden, Arbisi-Kelm, & Pomper, 2022; Scott & Fisher, 2012; Vlach & Debrock, 2017; 2019). In typically developing populations, children with robust language skills typically 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 typically poorer relative to XSWL performance in typically developing children (Hartley et al., 2020; McGregor et al., 2022, but see Venker, 2019). Therefore, we hypothesized that if XSWL is sensitive to weaknesses in 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 simultaneous exemplar-speaker input (our manipulation to increase input variability) would disproportionately 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 not with formal DLD diagnoses, 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. Utilizing a continuous versus a categorical approach to defining language ability is arguably a more robust analytical strategy 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 influences XSWL performance under increased input variability.

Variability

In the statistical learning literature, increased input complexity has been shown to decrease learning performance (e.g., Jost, Brill-Schuetz, Morgan-Short, & Christiansen, 2019;

Yu & Smith, 2007). For example, Jost et al., (2019) found that grammatical complexity impacted how adults learned and retained grammatical regularities in an artificial language. In their study, adults who were trained with shorter, simpler sentences exhibited significantly better learning and retention of grammatical regularities than adults who were trained with longer, more complex sentences. Similarly, Yu and Smith (2007) observed superior cross-situational word learning when adults were exposed to fewer word-referent pairs per trial. Adults word-learning performance was more robust when they were exposed to only two word-referent pairs per trial compared to four word-referent pairs. Decreased statistical learning performance has also been demonstrated under conditions of increased attentional load (Crespo & Kaushanskaya, 2022; Toro, Sinnett, & Soto-Faraco, 2005; 2011), suggesting that associative learning mechanisms may be sensitive to increased demands beyond those imposed by the complexity of the statistics-to-be-learned. Other studies, however, have not found evidence supporting the notion that input complexity shapes statistical learning outcomes (e.g., Musz, Weber, & Thompson-Schill, 2015). Therefore, it remains an open question whether complexity in the input confers computational advantages or disadvantages for statistical learning.

In the present study, we examined complexity in the form of variable input. Variability was simultaneously manipulated along two dimensions – speakers and exemplars – to maximize the effect of complexity (should it be observed), and to examine how fluctuations in bilingual experience and in language ability impact children’s ability to learn and generalize cross-situational statistics under complex variability conditions. We hypothesized that input variability may interfere with children’s XSWL performance. In the psycholinguistics literature, speaker variability is associated with processing costs for speech perception (i.e., lower accuracy and/or increased response times; Choi & Perrachione, 2019; Lim, Shinn-Cunningham, & Perrachione,

2019), particularly in children (e.g., Creel & Jimenez, 2012; Ryalls & Pisoni, 1997). Some models of speech processing posit that performance costs associated with processing multiple speaker input reflects increased cognitive effort of attentional switching from one speaker to another (Choi & Perrachione, 2019; Lim et al., 2019). Therefore, based on interference models of speech processing, it is plausible that simultaneous exemplar-speaker variability may impose higher demands on learning, interfering with the acquisition of co-occurring statistical regularities.

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. For example, children with lower levels of bilingual experience and language ability may benefit from input variability to a greater degree than children with higher levels of bilingual experience and language ability. If so, then we would expect to see greater performance increases in the high variability condition for children with lower levels of bilingual experience and language ability than for children with more robust abilities. Indeed, there is some evidence to suggest that input variability may be especially useful to typically developing children with weaker cognitive processing capacities (Crespo & Kaushanskaya, 2021).

While we broadly equated increased variability with increased complexity, and therefore anticipated the high-variability condition to be more challenging, we also considered the possibility that input variability might enhance XSWL. Apfelbaum & McMurray (2011) grounded facilitative effects of input variability in principles of early theories of learning and posited that variability of irrelevant cues draws attention to the invariant structures in the signal (e.g., Restle, 1955). For example, in the case of multiple talker input, fluctuations in speech productions across speakers aids learners in segregating irrelevant cues, like talker-specific

characteristics, from relevant cues, like acoustic boundaries differentiating similar sounding word forms (e.g., Rost & McMurray, 2010). In a similar fashion, exemplar variability is theorized to foster broad category representations by highlighting the invariant features that are core to a category (e.g., Mandler, Fivush, & Reznick, 1987). In both instances, broader representations are theorized to facilitate generalization.

Therefore, input variability may bolster children's encoding of novel word forms, facilitating word-referent mapping during XSWL and generalization to a novel speaker and object exemplar. If so, then children might display superior XSWL performance in the high variability condition compared to the low variability condition. It is possible that children with low and high levels of bilingual experience and language ability may equally benefit from input variability. Another possibility is that children with robust abilities might capitalize on facilitative effects of input variability and display greater performance increases in the high variability condition than children with lower levels of abilities.

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 current study included 37 typically developing Spanish-English bilingual participants (17 boys) aged 5 – 8 years. 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 was used as proxy for SES and was collected through the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 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)	1 – 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
	n	
<u>Child's Dominant Language</u>		
English	22	
Spanish	3	
English & Spanish equally	12	
<u>Language Mostly Spoken at Home</u>		
English	12	
Spanish	15	
English & Spanish equally	10	

^a Visual Matrices subtest, Kauffman Brief Intelligence Test – 2nd Edition

^b Core Language Index Score from Clinical Evaluation of Language Fundamentals – 5th Edition (CELF-5)

^c Core Language Index Score from Clinical Evaluation of Language Fundamentals – 4th Edition, Spanish (CELF-4 Spanish)

^d Expressive One-Word Picture Vocabulary Test – 4th Edition (EOWPVT-4)

^e Expressive One-Word Picture Vocabulary Test – 4th Edition, Spanish-Bilingual Edition (EOWPVT-4 SBE)

Standard Measures

The Clinical Evaluation of Language Fundamentals – Fifth Edition (CELF-5; Wiig, Semel, & Secord, 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, Semel, & Secord, 2006) was used to evaluate children’s expressive and receptive language skills in Spanish.

Language ability was indexed by children’s highest Core Language Index standard score from either CELF-5 or CELF-4 Spanish (Crespo, Gross, & Kaushanskaya, 2019; Crespo & Kaushanskaya, 2022). 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 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. 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. 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.

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 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.

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 ($\alpha_{standardized} = 0.76$; $r_{average} = 0.61$) 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. While conceptual vocabulary scores from the EOWPVT-SBE would, in theory be a viable alternative, in reality these scores alone proved problematic. Specifically, most children answered test items only in English, which created a skewed distribution of standard scores with a median of 140 and a mean of 134.61. As a result, conceptual vocabulary scores from the EOWPVT-SBE did not appropriately quantify vocabulary skills in the current sample.

We also computed a bilingual experience composite score ($\alpha_{\text{standardized}} = 0.88$; $r_{\text{average}} = 0.79$) 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 ($\alpha_{\text{standardized}} = 0.68$; $r_{\text{average}} = 0.42$) 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 ($r = 0.25$, $t(35) 1.52$, $p = 0.14$).

Experimental Task

Children completed a XSWL task in two experimental conditions. All experiments were administered via Gorilla (<https://gorilla.sc>), an online platform for building and hosting experiments online.

Stimuli. Two lists of 5 English-like novel words were retrieved from the Gupta et al. (2004) database. Words were matched on English and Spanish biphone probability and neighborhood density (calculated from the online CLEARPOND Database) across lists. Novel colorful objects

were selected from the Horst & 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 condition. See Appendix A for the lists of word-object pairings by order and condition.

Conditions. The two experimental conditions were: 1. Low variability condition, where children were exposed to one exemplar labeled by one female speaker; 2. 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, color, 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.

Speakers. Novel words were produced by 12 native English speakers from different regions in the United States between the ages of 18 – 40. Speakers included 7 females and 5 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 the exposure phase, children were instructed to look, listen, and learn the names of new toys (i.e., novel objects). No information about which word labeled which object was provided at any point during the exposure phase. 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. The testing phase followed immediately after the completion of the exposure 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 test were produced by a different female speaker not heard during the exposure phases. 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. See Appendix B and C for methodological details, such as presentation timings of the trials.

Analytical Approach

Two separate logistic mixed effects models were constructed in RStudio, version 1.2.5001 (RStudio Team, 2019) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) to examine the extent to which predictors increased or decreased children's likelihood (log-odds) of making an accurate response. In separate models, accuracy data was regressed on condition (contrast coded, (-.5, .5); low variability vs. 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, Levy, Scheepers, & Tily, 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, by-subject random slopes for Condition.

Results

Results revealed that children learned word-object pairs above chance levels (i.e., .50) in the low 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; $t(36) = 5.52$, $p < .001$).

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	MS ^f	ME ^g
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			
Multiple Speaker Condition	-0.03	0.33*	-0.29	0.05	0	0.06	0.33*	0.23	0.19	-0.05		
Multiple Exemplar Condition	0.25	-0.11	-0.44**	0.33*	-0.12	0.04	0.04	0.1	0.48**	0.17	0.38*	
Combined Cue Condition	0.34*	0.03	-0.32	0.24	0.05	0.21	0.14	0.24	0.39*	0.14	0.02	0.42**

^a Visual Matrices subtest, Kaufman 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

^f MS = Multiple Speaker Condition

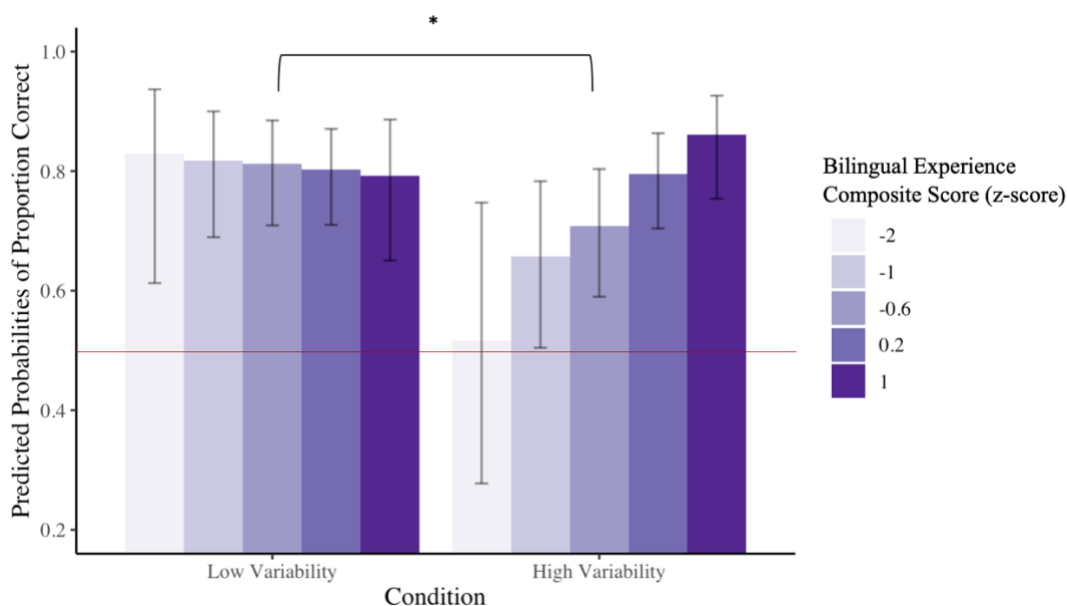
^g ME = Multiple Exemplar Condition

Table 3. Average Frequency and Duration Characteristics for Speakers

	Fundamental Frequency (F0, Hz)	Minimum Pitch (Hz)	Maximum Pitch (Hz)	Word Duration (seconds)
Low 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

Logistic mixed effects model results revealed a significant interaction between condition and bilingual experience composite score ($B = 0.67$, $SE = 0.33$, $z = 2.05$, $p < .05$; *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 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 low 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.

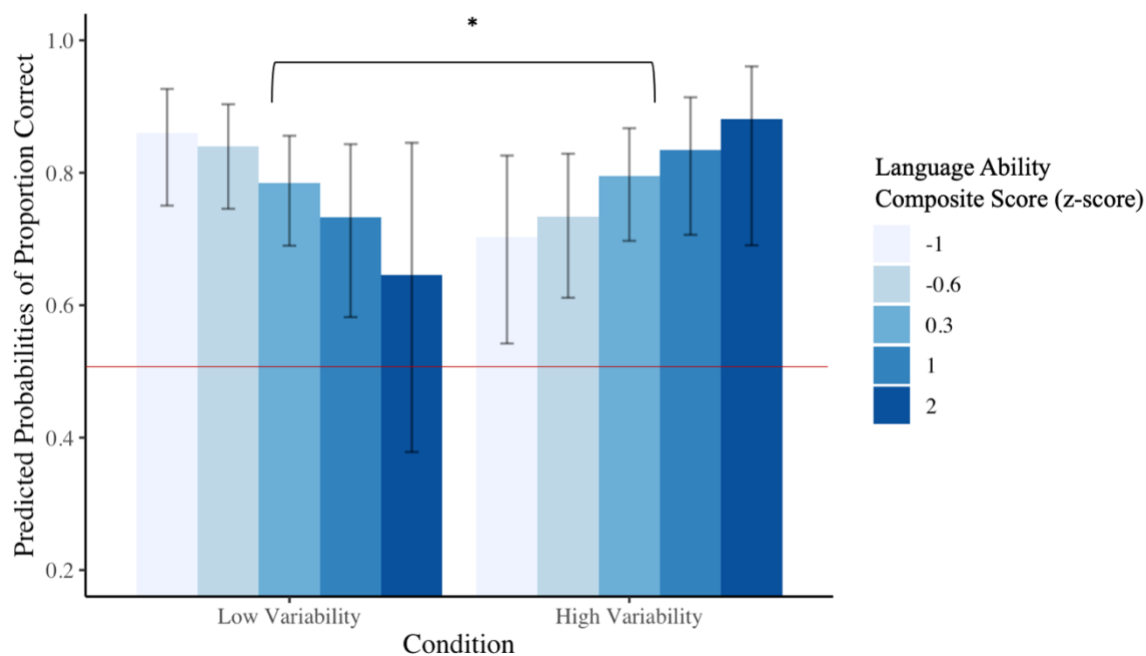
Figure 1. Condition and Bilingual Experience Composite Score Interaction



Note. Fitted model values for the Condition ~ Bilingual Experience Composite Score interaction term in the full model. Red line depicts chance levels (i.e., .50).

* $p < .05$

Figure 2. Condition and Language Ability Composite Score Interaction



Note. Fitted model values for the Condition ~ 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

	<i>B (SE)</i>	<i>z</i>	<i>Odds Ratio</i>	<i>95% CI</i>
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

* $p < .05$

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 low 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). XSWL performance remained at similar levels across low and high variability conditions for children with strong language skills but significantly decreased for children with weaker language skills. Language ability did not significantly predict children's XSWL in the low 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 low and high language ability composite scores. Specifically, compared to performance in the low variability condition, XSWL performance decreased in the high variability condition for children with weaker language skills but increased for children with stronger language skills.

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, allowing us to circumvent methodological issues associated with identifying language impairment in children with diverse histories. Results revealed graded effects of 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 complexity 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 word-learning advantages under increased variability in the current study is unclear and untested. However, one reasonable hypothesis is that variability in the input 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 the present study, children with stronger language skills were also more likely to learn word-referent mappings than children with weaker language skills in the high variability condition than the low 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. 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 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 & Kaushanskaya, (2022) 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.

A central hypothesis of the current study was that input variability would increase learning demands, and interference 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 low 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 & 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, it was sufficiently challenging to engender effects of bilingual experience and language ability on XSWL performance under increased variable input.

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 for some children.

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Chapter 5: General Discussion

The central goal of this dissertation was to determine the effects of input variability on XSWL in 5 – 8-year-old children with different language histories and language abilities. Variability was experimentally manipulated in two dimensions: speaker identity and category structure. **Experiment 1** examined the separate and combined effects of speaker and exemplar variability on XSWL performance in monolingual English-speaking children. **Experiment 2** examined the effects of bilingualism on XSWL under the different variability conditions. Word-learning performance in bilingual children was compared to word-learning performance in demographically matched monolingual children. **Experiment 3** examined XSWL in bilingual children only and tested whether individual differences in bilingual experience, language ability, or both moderated XSWL performance in low and high variability conditions.

Summary of Results

Overall, children learned and generalized co-occurring statistical regularities via XSWL above chance levels when the input varied in a single dimension (i.e., exemplars or speakers;) and in multiple dimensions (i.e., exemplars and speakers simultaneously). Variability in a single dimension did not facilitate nor hinder XSWL. However, results revealed that variability in multiple dimensions modulated XSWL performance, but the degree and direction of influence (i.e., positive or negative) largely depended on individual differences in bilingual experience and language ability.

Specifically, in **Experiment 1**, which focused on XSWL in monolinguals only, variability in multiple dimensions hindered children's XSWL performance. In **Experiment 2**, which compared monolinguals and bilinguals, results revealed bilingual word learning advantages when variability was present in the input. Compared to monolinguals, bilinguals were

significantly more likely to learn word-referent associations when the input varied in multiple dimensions (i.e., exemplars and speakers simultaneously). In **Experiment 3**, which focused on bilingual children only, results revealed graded effects of bilingualism and language ability on XSWL under increased learning demands. When the input varied in multiple dimensions, word-learning performance significantly increased as children's length of bilingual experience and language skills increased. Increased input variability decreased XSWL for children with less bilingual experience and weaker language skills.

Taken together, the experiments in this dissertation are the first to demonstrate that XSWL mechanisms can scale to accommodate variability in exemplars and in speakers, separately and when combined. Results from this work suggest that for some learners, accommodating variability in multiple dimensions may interfere with word learning. However, bilingual experience and robust language abilities may mitigate the adverse effects of accommodating variability in multiple dimensions during XSWL.

Input Variability and Individual Differences

In this dissertation, no evidence was found to support the hypotheses that variability in a single dimension (i.e., exemplars or speakers) would facilitate XSWL. The lack of facilitative effects of variability in a single dimension contrasts with literatures demonstrating that training with variable category exemplars (e.g., Ankowski, Vlach, & Sandhofer, 2013; Gentner, Loewenstein, & Hung, 2007; Namy & Genter, 2002; Perry, Samuelson, Malloy, & Schiffer, 2010; Twomey, Ranson, & Horst, 2014) and exposure to multiple speaker input (e.g., Apfelbaum & McMurray, 2011; Höhle, Fritzsche, Meß, Phillip, & Gafos, 2020; Richtsmeier, Gerken, Goffman, & Hogan, 2009; Rost & McMurray, 2009; 2010; Quam, Knight, & Gerken, 2017) bolsters word learning and generalization. This finding also contrasts with the small number of

studies suggesting that statistical learning mechanisms in children are sensitive to facilitative effects of variability (e.g., Gómez, 2002; Graf Estes & Lew-Williams, 2015; Suanda, Mugwanya, & Namy, 2014).

There may be a few methodological reasons why null effects of input variability in a single dimension were observed. Perhaps variability may need to be integrated in the statistical structure of the input to engender an effect. In studies that have found a facilitative effect of speaker variability, for example, speaker identity was linked to different statistical patterns, and provided cues that helped learners separate and segment multiple sets of regularities (e.g., Antovich & Graf Estes, 2018; Benitez, Bulgarelli, Byers-Heinlein, Saffran, & Weiss, 2020; Weiss, Gerfen, & Mitchel, 2009). Similarly, in the XSWL literature, variations in perceptual features have been manipulated to index higher-order regularities between words and categories, facilitating category learning and generalization in adults (i.e., Chen, Gershkoff-Stowe, Wu, Cheung, & Yu, 2017; Chen, Zhang, & Yu, 2018). An alternative explanation is that variability in a single dimension may have been too easy for school-aged children to yield facilitatory effects on learning. Whatever the reason for null effects, the findings are not in line with the variation theory of learning (e.g., Apfelbaum & McMurray, 2011; Gibson & Gibson, 1955; Restle, 1955). Nevertheless, naturalistic language input contains both variability that highlights structure and changes in the input, as well as surface-level variability that is superficial. Our findings suggest that XSWL mechanisms can scale to accommodate surface level exemplar and speaker variability without consequence to learning when they are separated in the input.

Critically, when variation occurred in multiple dimensions (i.e., exemplars and speakers simultaneously), word learning was significantly hindered in monolingual children (Experiment 1). These results are broadly in line with a growing number of studies suggesting that increased

input complexity may decrease statistical learning performance (e.g., Jost, Brill-Schuetz, Morgan-Short, & Christiansen, 2019; Yu & Smith, 2007). One interpretation of these findings is that variability in multiple dimensions may have increased attentional and/or processing demands, interfering with the disambiguation of word-object mappings. This interpretation is consistent with models of speech processing that posit performance costs associated with increased attention switching when processing multiple speaker input (e.g., Choi & Perrachione, 2019).

Evidence for interference effects of input variability in multiple dimensions was also observed in bilingual children with weaker language abilities (Experiment 3). This result is in line with recent work demonstrating that children with weaker language skills within the normal range of language ability may have difficulties learning statistical regularities under increased learning demands (Crespo & Kaushanskaya, 2022). If increased variability increased the cognitive load, as theorized above, then poorer performance in children with lower levels of language ability may have also reflected subtle weaknesses in cognitive skills, like attention (e.g., Gandolfi & Viterbori, 2020; Pauls & Archibald, 2016). Linking poorer XSWL performance with weaknesses in cognitive abilities, like attention, aligns with recent research demonstrating that individual variation in attention (Bhat, Spencer, & Samuleson, 2021; Pereira, Smith, & Yu, 2014; Yu, Suanda, & Smith, 2019) and memory capacity (e.g., Bhat et al., 2013; Vlach & DeBrock, 2017; 2019) within the normal range can constrain XSWL performance in children. Whatever the mechanism of interference, together, results suggest that variability in multiple dimensions (i.e., speakers and exemplars) may confer computational disadvantages for XSWL in all monolingual children but only in bilingual children with weaker language abilities. Conversely, the increased learning demands associated with accommodating variability in

multiple dimensions may have been precisely the conditions that fostered bilingual word learning advantages in Experiment 2 and Experiment 3.

Bilingualism and Learning Under Increased Demands

In Experiment 2, bilingual children were more likely to learn word-referent mappings when the input varied in multiple dimensions than monolingual children. Superior word learning under conditions of increased variability in bilingual children was also observed in a graded manner in Experiment 3. Higher levels of bilingual experience were associated with higher levels of XSWL performance under conditions of increased input variability. These findings are in line with the broader statistical learning literature, where bilingual advantages are most consistently observed under conditions of increased complexity, such as when tracking statistics for multiple structures, multiple competing cues, or remapping words (e.g., Antovich & Graf Estes, 2018; Beneitez, Yurovsky, & Smith, 2016; Kovács & Mehler, 2009; Poepsel & Weiss, 2016; Wang & Saffran 2014). The current dissertation findings extend this body of work and suggests that bilingualism may also facilitate the learning of co-occurring statistics between words and their referents in the presence of exemplar and speaker variability, especially when the cues are combined.

Accommodating input variability during XSWL, particularly in multiple dimensions, may have loaded more heavily on processes that are enhanced in bilinguals, such as working memory (Eviatar, Taha, Cohen, & Schwartz, 2018; Kaushanaskaya & Marian, 2009), and inhibition (e.g., Darcy, Mora, & Daidone, 2016; Warmington, Kandru-Pothineni, & Hitch, 2019; Yoshida, Tran, Benitez, & Kuwabara, 2011). Such advantages may explain why bilinguals learned more word-referent associations than monolinguals in Experiment 2. Moreover, recent evidence that bilingualism may have a graded effect on the development of cognitive skills

(Sorge, Toplak, & Bialystok, 2017; Chung-Fat-Yim, Sorge, & Bialystok, 2020) might also explain why performance increased as bilingual experience increased in Experiment 3.

However, the degree to which bilingualism enhances cognitive processes, and the degree to which those processes influence XSWL, remain open questions, ones that likely depend on the task and manipulation undertaken (Ware, Kirkovski, & Lum, 2020) as well as the age (Ware et al., 2020) and type of bilingual examined (Kalia, Wilbourn & Ghio, 2014, but see Paap, Johnson & Sawi, 2014). Indeed, there are a lot of methodological issues associated with defining bilingualism and examining its effects on cognition (e.g., Kaushanskaya & Prior, 2015; Marian & Hayakawa, 2021). In this dissertation, we indexed bilingualism categorically (Experiment 2) and continuously (Experiment 3) and found evidence to suggest that bilingual language experience may influence XSWL mechanisms under increased variability demands.

Theoretical and Practical Implications

Results from this dissertation provide supporting evidence for the validity of XSWL mechanisms in conditions of increased input variability in diverse learners. Results also suggest that variability in multiple dimensions could be considered a form of input complexity, one that may confer computational disadvantages for children with monolingual language experience and bilingual children with weaker language skills. Indeed, given that the majority of XSWL research has been conducted in adults, this work also highlights language ability as a developmental system that supports word learning under increased learning demands.

Moreover, this dissertation provides indirect evidence in support of dual-system theories of statistical learning. These theories generally posit that cognitive-dependent explicit process may support automatic implicit processes in the learning of more complex statistical patterns (e.g., Batterink, Reber, Neville, & Paller, 2015; Daltrozzo & Conway, 2014). The data in this

dissertation suggest that at least some components of XSWL may be dependent on cognitive processes. If it were not so, learning may not have been sensitive to manipulations that increased cognitive effort and to individual differences in children's language histories and language abilities (i.e., factors that are associated to individual differences in cognitive abilities). An alternative interpretation of the results might instead suggest that XSWL mechanisms may have a limited capacity to flexibly adapt to input variability at this stage in development, or in general. Overall, the findings of the current dissertation contribute to our understand of how input characteristics and learner characteristics interact and modulate XSWL performance.

This dissertation also contributes to the debate on the effects of bilingualism on statistical learning. The findings echo arguments put forth that bilingualism may not alter core statistical learning abilities (e.g., Weiss, Schwob, & Lebkuecher, 2020). Rather, bilingual language experience may prime learners to manage uncertainty in the input more efficiently than monolingual language experience under conditions of increased demands. This dissertation corroborates this theorizing with evidence from a XSWL paradigm with groups of demographically matched bilingual and monolingual children.

The practical implications of this work are that for some children, consistency in the language input may be key to better learning outcomes. Variability in a single dimension of the input may be tolerated, but for children with weaker abilities, variability in multiple dimensions may undermine learning when learning is exposure-based with no feedback. More research is needed to determine whether this pattern holds for children with more variable linguistic experiences (e.g., less English proficiency) and children with lower levels of language ability. Nonetheless, results from this work inch us one step closer to achieving the long-term goal of

identifying input conditions that optimize the input for children with reduced language exposure and language weaknesses.

Limitations and Future Directions

Some methodological considerations are important to point out when interpreting the findings. The first consideration is that all experimental data was collected online via Zoom. Although all participants were in a quiet space, and the experimenter was present online, miscellaneous distractions would sometimes interfere with testing. The lack of experimental control may have influenced word learning outcomes for some children, particularly for children with lower levels of language ability.

Another limiting factor is that there was only one test speaker for all conditions. Children may have familiarized themselves with the test speaker after completing the first condition, making generalization from exposure to test easier for subsequent conditions. Critically, exposure speakers were always different than the test speaker and condition order was counterbalanced across participants. Still, using the same test speaker may have influenced word generalization outcomes. However, using the same test speaker for all conditions provided the advantage of controlling for cross-speaker variation across speakers.

Sample demographics, and specifically the fact that language ability was constrained to the normal range limits our ability to extend the findings to children with language impairments. Although XSWL performance decreased in the high variability condition in children with weaker language skills, a simple effects analysis revealed that language ability was not predictive of word learning performance in the high variability condition specifically. Given that there were only a few children with below average language composite scores, we may have been underpowered to observe an effect of language ability on XSWL when the input varied in

multiple dimensions. Examining word learning in one condition (i.e., high variability condition), as opposed to two conditions (i.e., low variability condition relative to high variability condition) also reduced the number of observations in the simple effects analysis, effectively reducing power. It is likely that input variability, especially in multiple dimensions, may have distinct consequences for children with a true language impairment. Therefore, future directions include examining XSWL under different variability conditions in a sample of children with Developmental Language Disorder.

In addition to examining a lower range of language ability, future directions also include examining a wider range of bilingual abilities. The focus would be on emerging bilingual children with less English exposure and bilingual experience (unlike the majority of the children in this dissertation, who acquired English and Spanish from birth). The main research questions would center on whether different patterns of facilitative effects (or interference effects) would emerge when targets are in the non-dominant language (i.e., English). Another question is whether similar word learning advantages would be observed in bilinguals with less balanced profiles. Answers to these empirical questions would further our understanding of how different aspects of experience and ability interact with input variability to influence XSWL performance.

Another consideration for future research is to examine whether different variability manipulations have distinct consequences for XSWL at different time scales. The current work focused on immediate retention. Might facilitative effects have been observed with a delay in recall? Testing at a delayed interval would reveal whether input variability might impact how learners retain and retrieve words.

Interpreting facilitative and interference effects in the current work proved challenging without direct measurements of children's cognitive abilities. Collecting these measures

remotely is difficult given that many rely on reaction time data analyses. Therefore, future directions also include examining how accommodating variability in exemplars and speakers interact with domain-general cognitive processes to influence XSWL performance. Specifically, measurements of attention, shifting, short term memory, and working memory will be collected in person and examined for their predictive role in XSWL performance under different variability conditions.

Conclusions

In conclusion, this dissertation provides the first empirical evidence that children can learn and generalize word-referent mappings to novel object exemplars via XSWL when exposed to multiple exemplars and multiple speakers. The results suggest that variation in the input and variation in the learner interact to modulate mechanisms of lexical learning. Overall, while robust against variability in single dimensions, XSWL mechanisms may be sensitive to the cognitive burden associated with variability in multiple dimensions in some learners. Together, the results from this work provide new theoretical insights into how fundamental mechanisms of word learning scale to accommodate more complex and naturalistic forms of input. These findings inform current models of lexical acquisition, which rarely account for learning in diverse populations or for input variability.

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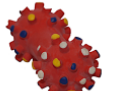
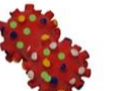




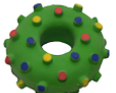

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Appendix A











Word-Object Pairs by Order and Condition

A1. Word-Object pairs for conditions that used only one exemplar during the learning phase

Order A: No Variability Condition Order B: Multiple Speaker Condition			Order A: Multiple Speaker Condition Order B: No Variability Condition		
Novel Word	Novel Object		Novel Word	Novel Object	
	Exposure Item	Test Item		Exposure Item	Test Item
Gonepe			Gabek		
Basim			Bilob		
Kemig			Kadad		
Dofege			Denose		
Tinuf			Tafat		





















Note. Items used in the low variability condition in Experiment 3.

A2.1. Word-Object pairs for conditions that used multiple exemplars

Order A: Multiple Exemplar Condition			
Order B: Combined Cue Condition			
Novel Word	Novel Object		
	Exposure Item		Test Item
Gitin			
Bukese			
Kenofe			
Dadele			
Tosik			

Note. Items used in the high variability condition in Experiment 3.

A2.2. Word-Object pairs for conditions that used multiple exemplars

Order A: Combined Cue Condition				
Order B: Multiple Exemplar Condition				
Novel words	Novel Objects			
	Exposure Items			Test Item
Gesud				
Botak				
Kotase				
Didep				
Tegine				

Note. Items used in the high variability condition in Experiment 3.

Appendix B

Example Exposure and Test Trials by Condition for Order A

Exposure Phase Trials

1. No Variability Condition – Female Speaker 1 produced all the words

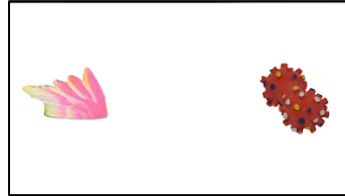
Gonepe

Tinuf



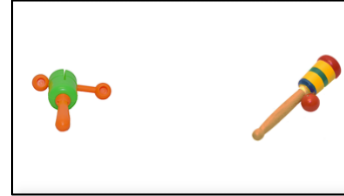
Basim

Dofege



Gonepe

Kemig



Test Phase Trial^a

Novel Object Exemplars

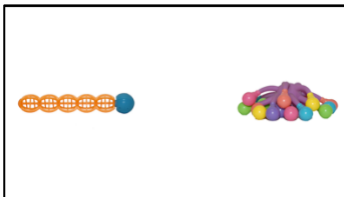
Tinuf



2. Multiple Exemplar Condition – Female Speaker 2 produced all the words

Kenofe

Gitin



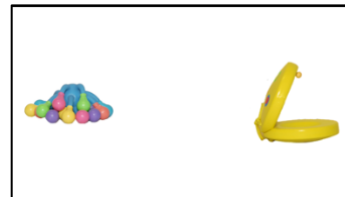
Tosik

Dadele

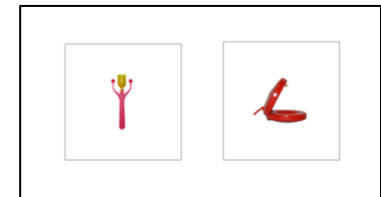


Gitin

Tosik

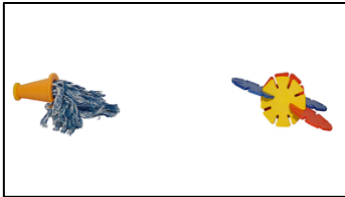


Dadele

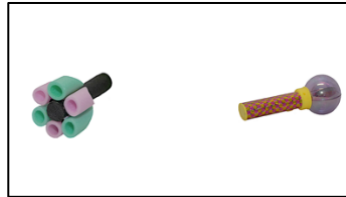


3. Multiple Speaker Condition – Words produced by 5 Female and 5 Male Speakers

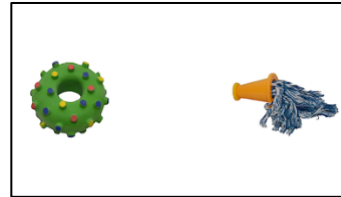
Bilob (F3)^b Gabek (M1)^c



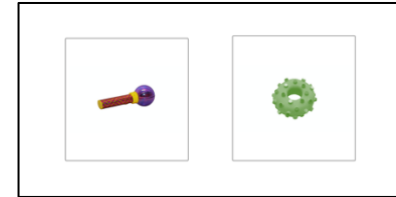
Kadad (F7) Denose (F4)



Bilob (M8) Tafat (F6)



Tafat

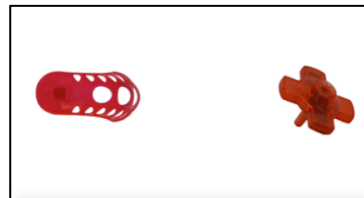


4. Combined Cue Condition – Words produced by a different set of 5 Female and 5 Male

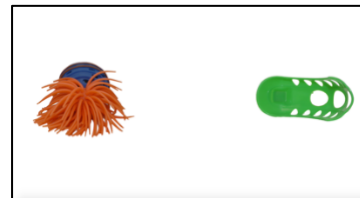
Botak (F8) Kotase (M4)



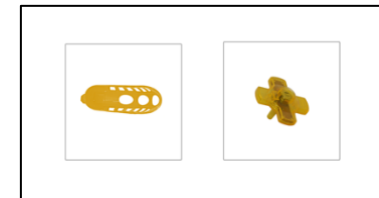
Gesud (F10) Botak (M3)



Gesud (M4) Kotase (F9)



Gesud



Note. This graphic depicts three exposure trials and one test trial for each condition for Order A. Word Lists and Picture Lists were counterbalanced to create other permutations of each condition for Order B (See Appendix A). The first word produced in each trial did not always label the left-centered object first. In these instances, the first word produced labeled the right-centered object and the second word produced labeled the left-centered object.

^a Female Speaker 13 produced all test words

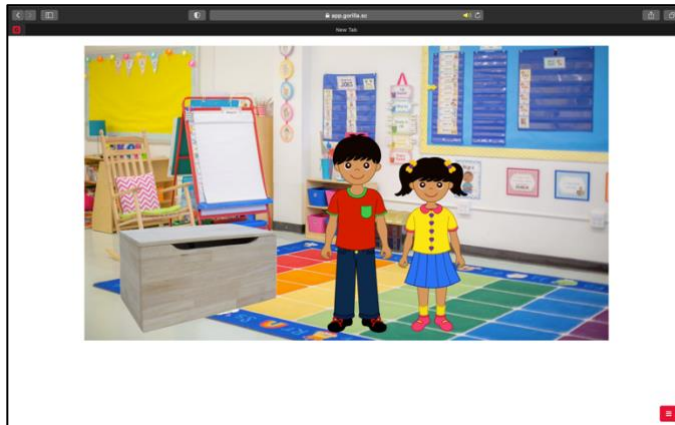
^b (F3) = Female Speaker 3

^c (M1) = Male Speaker 1

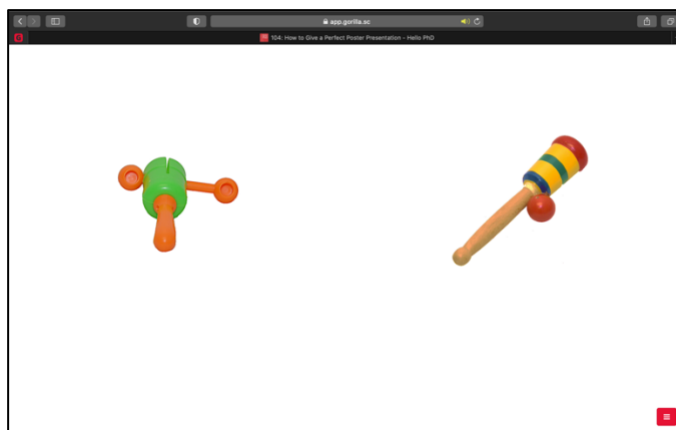
Appendix C

Methodological Details for Exposure and Test Trials

C1. Exposure Phase



Instructions: *“Hi! Let’s play a game! In this game, you’ll see some new toys. To win this game, you’ll have to learn the names of these new toys! Let’s look!”*



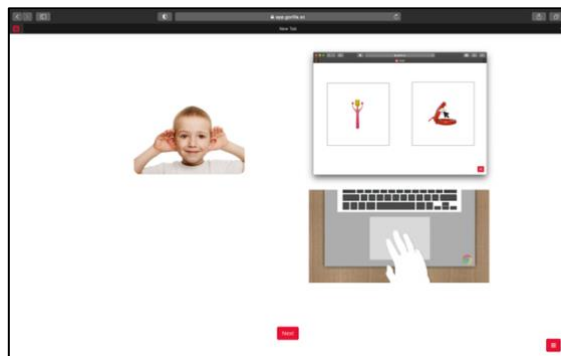
“Gonepe”
(0 ms)

“Kemig”
(2000 ms)

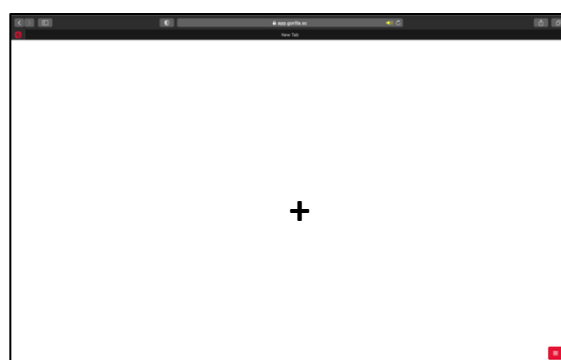
Time in Trial (6000ms)

Note. Instructions were only presented once at the beginning of the task. After, in each exposure trial, two objects were presented, and the first novel word was produced at trial onset (i.e., 0 ms). The second novel word was produced 2000 ms after trial onset. Each exposure trial was approximately 6000 ms.

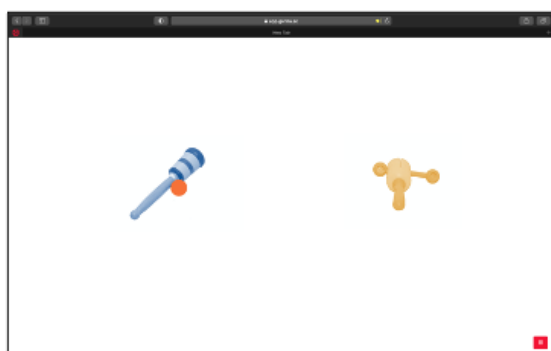
C2. Test Phase



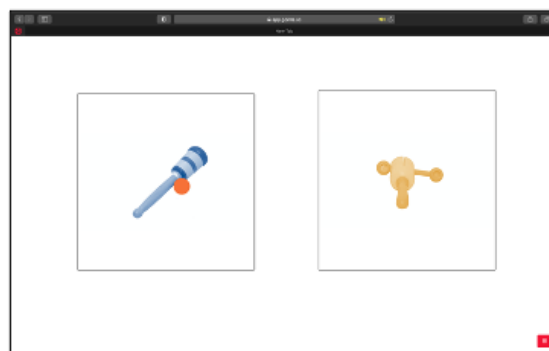
Instructions: *“Listen to the word and pick the picture that matches the word.”*



(500 ms)



(On screen 0 ms - 2000 ms)



“Kemig”
(2100 ms)

0 ms

8000 ms

Note. Test instructions were only presented once at the beginning of the test phase. A 500 inter-stimulus interval was presented before each test trial. At the beginning of each test trial, two objects appeared on screen. The target word was produced once at 2100 ms, and response buttons would immediately appear around the novel objects. Participants had 4000ms after word onset to select a novel object. Each trial was approximately 8000 ms.