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The Effects of Bilingualism on Children's Cross-Situational Word Learning Under Different Variability Conditions

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Introduction

Despite high referential ambiguity, children show a remarkable capacity to acquire new words from the linguistic input they receive. One process 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 evidence for the robustness 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 children's 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; Kaushanaskaya, 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. However, Alt and colleagues (2013; 2019) have reported that bilingual children may be less sensitive to sounds patterns when learning novel words than monolingual children. Therefore, in the present study, we asked whether bilingual language experience would yield facilitative or interference effects on XSWL performance.

As noted by McGregor and colleagues (2022), the literature on XSWL has paid little attention to how individual differences in learner characteristics contribute to XSWL performance. Their findings suggest that children with different language abilities may rely upon different mechanisms to support their word learning, leaving open the question of whether language experience also influences 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 no word learning performance differences among monolinguals, English-Spanish bilinguals, and Mandarin-English bilinguals when participants needed to learn 1-to-1 mappings. 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. 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

Objects of the same category share a representation, but individually, they usually differ from one another in their perceptual properties. Studies have shown that children as young as 3 months old can accommodate exemplar variability, and construct categories for unfamiliar objects when exposed to varying exemplars (e.g., Bornstein & Mash, 2010). Many empirical studies have demonstrated 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). In treatment studies, findings suggest that incorporating object variability into language intervention improves children's retention of newly learned words (Aguilar, Plante, & Sandoval, 2018; Alt, Meyers, Oglivie, Nicholas, & Arizmendi, 2014; Nicholas, Alt, & Hauwiller, 2019). However, in a recent study, Höhle, Fritzsche, Meß, Phillip, and Gafos (2020) found that different visual exemplars did not help young children learn similar sounding novel words. In all these studies, learning has been examined on tasks where objects and categories are ostensibly labeled. Consequently, much less is known about how exemplar variability influences word-referent mapping and category formation when learning hinges on aggregating co-occurring statistical regularities of the word form and category over time.

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 children can extract co-occurring regularities across varying exemplars to form categories. It also remains unclear whether exemplar variability bolsters XSWL performance. There is some evidence to suggest that children (Crespo &

Kaushanskaya, 2021; Suanda et al., 2014) and adults (Dautriche & Chemla, 2014; Kachergis, Yu, Shiffrin, 2009; Zettersten, Wojcik, Beneitez, & Saffran, 2018) may be sensitive to variability effects during XSWL. 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., Brojdeet al., 2012) whereas bilingual children capitalize more on social-pragmatic cues, like eye gaze (e.g., Brojdeet 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 is another form of variability that children consistently experience in day-to-day life. 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 et al., 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 (e.g., 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 facilitative 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 and 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 and 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. Nicholas et al., (2019) found that combining high variability for objects and labels when teaching preschoolers prepositions was not effective. Therefore, this manipulation may also 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

This study was reviewed and approved by XXX. Participants' legal guardians provided informed consent and children provided oral assent. All data collection was conducted remotely via Zoom. Data and r-scripts are available at: XXX.

Participants

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_{age} = 6.87; 14 boys) and 37 Spanish-English bilinguals (M_{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 around their first birthday (M_{months} = 12.05, SD_{months} = 18.35; *Range* = 0 – 54 months) and to Spanish at birth (M_{months} = 1.97, SD_{months} = 08.17; *Range* = 0 – 48 months). 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.

Design of 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 four exemplars. Three object exemplars were provided by the NOUN Database (Horst & Hout, 2016). One additional exemplar was created in PowerPoint by altering the image color from an existing exemplar. Across the four exemplars, there were fluctuations in color, shape, and size, but these fluctuations were not systematic. While all exemplars differed primarily by color, two exemplars of the same category could differ in both color and shape (i.e., solid colored heart-shaped slinky toy and a multi-colored triangle-shaped slinky toy), or color and size (i.e., solid colored noise maker and a multi-colored smaller noise maker). In each category, three object exemplars were randomly assigned to serve as exposure items and one as a test item. See Appendix A2 for a list of all exemplars used during the learning phase.

*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.

*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 same number of words was taught in each condition (i.e., 5 novel words per condition) and each of the 5 novel words in each condition was presented 10 times, equating the number of exposures to the words across conditions.

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. See Appendix C for presentation timings of the trials.

Data Processing & Analysis

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). Moreover, the addition of children's CELF-5 scores did not change the pattern of results in models examining the separate and combined effects of variability on XSWL performance.

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; $t(70) = 5.69$, $p < .001$, $d = 0.68$). See Table 3 for descriptive statistics for accuracy by Language Group and Condition.

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 (Figure 1). 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 4 for full model results of the main analyses.

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 ($z = 0.17$, $p = .87$, *Odds Ratio:* 1.05, *95% CI:* 0.56 – 1.97).

Additionally, model results revealed a significant main effect of English age of acquisition such that for a one unit increase in English age of acquisition (in months), the odds of correctly mapping a word-object pair significantly decreased 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). In other words, each additional increase of one month in English age of acquisition was associated with a 2% decrease in the odds of selecting the correct word-object pair at test. Table 5 for full model results of the simple effects analyses.

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) was compared to learning in a condition that varied in multiple dimensions (i.e., exemplars and speakers), bilingual word learning advantages were observed. Overall, bilinguals were more likely to learn word-referent associations than monolinguals when there was variability present in the input. Bilinguals were especially better than monolinguals at accommodating simultaneous exemplar-speaker variability during XSWL. In contrast, performance did not differ 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; Poepsel & 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; Poepsel & 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.

A question could be raised about whether the effects of bilingualism in the combined cue condition are meaningful if they are not present in the no variability condition. It is possible that bilingualism effects might not be present in the no variability condition because they were (a) smaller than in the combined condition, and thus not detected, or (b) that truly it takes multiple forms of variability to detect bilingualism effects. In either case, we do not believe that this diminishes our main argument that bilingualism may bolster learning under conditions of increased input variability.

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 is 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.

An alternative interpretation of our findings is that variability in multiple dimensions may have 'hurt' monolingual word learning, which is consistent with findings in Nicolas et al., (2019), while having little effect on bilingual word learning. Indeed, performance averages were relatively stable across conditions for bilinguals, whereas for monolinguals, performance decreased when the input varied in two dimensions. The one caveat here is that bilingual word learning performance decreased when children were exposed to multiple exemplars relative to performance in other conditions. It is unclear why bilinguals performed poorer in this condition, but any negative impact of multiple exemplars on bilingual word learning may have been attenuated by the presence of multiple speakers in the combined cue condition.

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, but see Höhle et al., 2020) and in language intervention studies designed on principles of statistical learning (e.g., Aguilar et al., 2018; Alt et al., 2014; Nicholas et al., 2019) may not extend to experimental 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 adaptions 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 exploring 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.

Conclusions

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. Specifically, these data suggest that some statistical learning processes may operate across domains to facilitate lexical acquisition, and that these processes may be modulated by linguistic experiences that facilitate the learning of more complex structure. In addition, 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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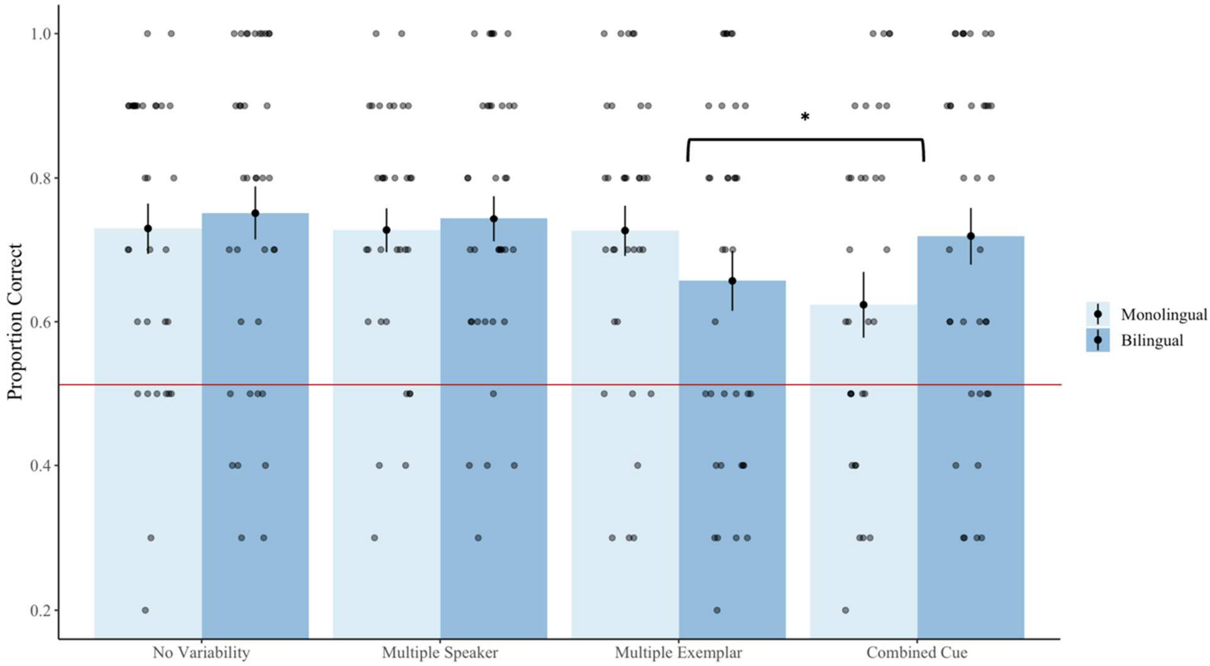
Figure 1

Bar Graphs Depicting Performance in Monolinguals and Bilinguals by Condition



Note. Error bars denote standard error. Red line depicts chance levels (i.e., .50). Means and Standard Errors reported in each bar.

$^{*}p < .05$, $^{**}p < .01$

Table 1

Participant Characteristics, M (SD)

	Monolinguals	*Range*	Bilinguals	*Range*	*t*
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	13.80***
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)	-	-
			n		
Child's Dominant Language					
English	-		22		
Spanish			3		
English & Spanish equally			12		
Language Mostly Spoken at Home					
English	-		12		
Spanish			15		
English & Spanish equally			10		

[a] Visual Matrices subtest, *Kauffman Brief Intelligence Test – 2nd Edition*

[b] 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)

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

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

Table 3

Accuracy by Language Group and Condition (Mean, Standard Error)

Condition	Monolinguals	Bilinguals
No Variability	0.73 (0.04)	0.75 (0.04)
Multiple Speakers	0.73 (0.03)	0.74 (0.03)
Multiple Exemplars	0.73 (0.04)	0.66 (0.04)
Combined Cue	0.62 (0.05)	0.72 (0.04)

Table 4

Full Model Results

	Model 1[a]		Model 2[b]	
Conditions:	**Reference**: No Variability Contrast 1: Multiple Speaker Contrast 2: Multiple Exemplar		**Reference**: Combined Cue Contrast 1: Multiple Speaker Contrast 2: Multiple Exemplar	
	B (SE)	***z***	***B (SE)***	***z***
Intercept	1.32 (0.19)	7.07	1.10 (0.20)	5.42***
Contrast 1	- 0.20 (0.19)	- 1.04	0.19 (0.25)	0.74
Contrast 2	- 0.30 (0.23)	- 1.32	0.03 (0.20)	0.14
Group	0.17 (0.30)	0.55	0.88 (0.35)	2.47*
English Age of Acquisition	-	-	-0.02 (0.01)	- 2.93**
Contrast 1 X Group	- 0.07 (0.36)	- 0.20	- 0.49 (0.42)	- 1.19
Contrast 2 X Group	- 0.54 (0.35)	- 1.53	- 0.95 (0.38)	- 2.47*
Observations	2120		2120	
Marginal R^2 /Conditional R^2	0.01/0.23		0.03/0.26	

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

[a] Final model formula: glmer(Correct ~ (dc1+dc2)*LangGrpC + (1+(dc1+dc2)|Participant.Public.ID) + (1|Answer), data=df.sb, family = binomial, control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

[b] Final model formula: glmer(Correct ~ (dc1+dc2)*LangGrpC + EngAoA + (1+(dc1+dc2)|Participant.Public.ID) + (1|Answer), data=df.cb, family = binomial, control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

Table 5

Simple Effects Full Model Results

	Model 1 [a]				Model 2 [b]			
Conditions:	**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*	3.28	2.23 – 4.83	1.10 (0.19)	5.75***	3.01	2.07 – 4.39
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
Observations	710				710			
Marginal R^2 /Conditional R^2	0.04/0.26				0.04/0.32			

[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

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$