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The effects of bilingualism on children's cross-situational word learning under different variability conditions

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A B S T R A C T

In the current study, we examined the separate and combined effects of exemplar and speaker variability on monolingual and bilingual children's cross-situational word learning performance. Results revealed that children's word learning performance did not differ when the input varied in a single dimension (i.e., exemplars or speakers) compared with 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 with a condition that varied in multiple dimensions (i.e., exemplars and speakers), bilingual word learning advantages were observed; 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.

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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 15 years, a growing number of empirical studies (Kachergis et al., 2012; Smith et al., 2011; Smith & Yu, 2008, Suanda et al., 2014, Vlach & Johnson, 2013; Yu & Smith, 2007), computational simulations (e.g., Vong & Lake, 2022), and data from parent–child interactions (Yu et al., 2021; Zhang et al., 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 et al., 2016; Crespo & Kaushanskaya, 2021; Escudero et al., 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 current 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, shape) and asked the question: 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, 2018; Singh et al., 2018), children (Alt et al., 2019; Eviatar et al., 2018; Kaushanskaya et al., 2014; Yoshida et al., 2011), and adults (Bogulski et al., 2019; Kaushanskaya, 2012; Kaushanskaya & Marian, 2009; Kaushanskaya & Rechtzigel, 2012; Kaushanskaya et al., 2013; Warmington et al., 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 such as inhibition—the ability to control attention and inhibit task-irrelevant information (e.g., Darcy et al., 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., 2013, 2019; Buac et al., 2016; de Diego-Lázaro et al., 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 aged 7 to 9 years 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 current study, we examined whether bilingualism affects XSWL performance. Compared with 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 (e.g., transitional probabilities, grammar rules, co-occurring regularities), and number of patterns to be learned (for a review, see Weiss et al., 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 bilinguals' 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 et al., 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) reported that bilingual children may be less sensitive to sound patterns when learning novel words than monolingual children. Therefore, in the current 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 on 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 with monolingual adults, bilingual adults were more accurate at mapping objects to novel words that had different sound patterns (i.e., bon vs. deet) as well as to 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 one-to-one 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., Fernald et al., 2013; Hoff, 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 current 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 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 et al., 2013; Gentner et al., 2007; Namy & Gentner, 2002; Perry et al., 2010; Twomey et al., 2014). In treatment studies, findings suggest that incorporating object variability into language intervention improves children's retention of newly learned words (Aguilar et al., 2018; Alt et al., 2014; Nicholas et al., 2019). However, in a recent study, Höhle et al. (2020) found that different visual exemplars did not help young children to learn similar sounding novel words. In all these studies, learning was examined on tasks where objects and categories were 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 et al., 2017, 2018; Gangwani et al., 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 et al., 2009; Zettersten et al., 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 versus 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 affect 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 et al., 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 et al., 2010; Byers-Heinlein & Werker, 2009; Houston-Price et al., 2010). Monolingual children have also been shown to depend more on common perceptual features such as shape to categorize objects (e.g., Brojde et al., 2012), whereas bilingual children capitalize more on social-pragmatic cues such as 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 with monolinguals. Alternatively, multiple exemplars may affect 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; Höhle et al., 2020; Quam et al., 2017; Richtsmeier et al., 2009; Rost & McMurray, 2009, 2010) 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., Bressler et al., 2014; Choi & Perrachione, 2019; Kishon-Rabin et al., 2009; Lim et al., 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 et al., 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 or for bilingual advantages in accommodating speaker variability during XSWL (Crespo & Kaushanskaya, 2021). In the current study, we included male speakers in addition to female speakers to create more acoustic variability than in Crespo and Kaushanskaya (2021) and to strengthen the effect of speaker variability if such an effect exists. We hypothesized that if speaker variability negatively affects 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 affects children's XSWL performance, then bilingual and monolingual children would 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 current study was whether bilingual children, compared with 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; Kovács & Mehler, 2009; Kuo & Anderson, 2012) 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; Kaushanskaya et al., 2014; Yoshida et al., 2011). Therefore, we hypothesized that bilingual children would demonstrate superior XSWL performance compared with monolingual children when multiple exemplars and speakers are combined and presented simultaneously in the input.

Method

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. Data and r-scripts are available at https://www.openicpsr.org/openicpsr/project/172882/version/V1/view.

Participants

A total of 77 children aged 5 to 8 years were recruited. Of these, 2 monolingual and 2 bilingual participants were excluded because they could not engage via Zoom. In addition, 1 monolingual and 1 bilingual participant were excluded because they failed to complete a second session to finish study tasks. The final sample included 34 English monolinguals (M_{age} = 6.87 years; 14 boys) and 37 Spanish–English bilinguals (M_{age} = 7.26 years; 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* = 12.05 months, *SD* = 18.35, range = 0–54) and to Spanish at birth (*M* = 1.97 months, *SD* = 08.17, range = 0–48). At the time of testing, on average, bilingual children were exposed to English 59.27% and to Spanish 40.73% of the time during their waking hours. Mother's years of education was used as a proxy for socioeconomic status and was collected through the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007). See Table 1 for participant characteristics.

Design of experimental task

Each child completed an XSWL task in four experimental conditions in a within-participant 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 five 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 and Hout (2016) Novel Object and Unusual Name (NOUN) database (second edition), which contains colorful novel objects normed on familiarity and name-ability scores. Word–object pairs were counterbalanced across condition. See Appendix A in the online Supplementary Material 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

Table 1
Participant characteristics: Means (and standard deviations).

	Monolinguals	Range	Bilinguals	Range	*t*
N	34 (14 boys)		37 (16 boys)		–
Age (years)	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 (8.17)	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 gominant language	–				
English			22		
Spanish			3		
English and Spanish equally			12		
Language mostly spoken at home					
English	–		12		
Spanish			15		
English and Spanish equally			10		

[a] Visual Matrices subtest of Kaufman Brief Intelligence Test–Second Edition (KBIT-2).
[b] Core Language Index Score from Clinical Evaluation of Language Fundamentals–Fifth Edition (CELF-5).
[c] Core Language Index Score from Clinical Evaluation of Language Fundamentals–Fourth Edition, Spanish (CELF-4 Spanish).
[***] $p < .001$.

color from an existing exemplar. Across the four exemplars, there were fluctuations in color, shape, and size, but these fluctuations were not systematic. Whereas 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 multi-colored triangle-shaped Slinky toy) or color and size (i.e., solid-colored noise maker and 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 of the United States from 18 to 40 years of age. Speakers included 13 female and 10 male adults. See Table 2 for average frequency and duration characteristics for each speaker.

Conditions

The four experimental conditions were (a) No Variability condition, where children were exposed to one exemplar labeled by one female speaker; (b) Multiple Exemplar condition, where children were exposed to three exemplars of each category labeled by one female speaker; (c) Multiple Speaker condition, where children were exposed to one exemplar labeled by five male and five female speakers (in this condition, each production of a word was labeled by a different speaker); and (d) Combined Cue condition, where children were exposed to three exemplars of each category labeled by five male and five 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.

Table 2
Average frequency and duration characteristics for speakers by condition.

	Fundamental frequency (F0, Hz)	Minimum pitch (Hz)	Maximum pitch (Hz)	Word duration (s)
Single speaker and Multiple Exemplar				
Female Speaker 1	256.90	158.66	278.09	0.97
Female Speaker 2	218.70	16 6.61	271.62	1.07
Multiple speaker and 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
$M_{Females}$	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
M_{Males}	121.49	97.80	132.02	0.92
Testing speaker				
Female Speaker 13	222.40	183.49	233.16	0.89

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 in the exposure phase. Each word–object pair was presented 10 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., five novel words per condition), and each of the five 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 two-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 2000 ms. Response buttons appeared around the novel objects, and participants had 4000 ms to select a novel object. All test objects were novel exemplars, and all target words were produced by a different female speaker not heard in any of the exposure phases. See Appendix B in the Supplementary Material for a list of example exposure trials and test trials in each condition. See Appendix C in the Supplementary Material for presentation timings of the trials.

Data processing and analysis

Two separate logistic mixed effects models were constructed in RStudio Version 1.2.5001 (RStudio Team, 2019) using the lme4 package (Bates et al., 2015) to examine the extent to which predictors increased or decreased children's likelihood (log odds) of making an accurate response. In both models, accuracy data were 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 with 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, $\chi^2(1) = 2.27$, $p = .13$, and current English language exposure, $\chi^2(1) = 2.43$, $p = .12$, did not significantly improve model fit, and therefore these were not included as covariates.

To examine the combined effects of exemplar and speaker variability on XSWL performance, in Model 2 the Combined Cue condition served as the reference condition and was compared with 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 of current English language exposure, $\chi^2(1) = 1.53$, $p = .22$, 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 et al., 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-participant random intercepts, by-participant random slopes for each contrast, and by-item random intercepts. The addition of age, mother's years of education, and nonverbal IQ did not significantly improve fit for either model (*ps* > .05). Moreover, the addition of children's Clinical Evaluation of Language Fundamentals–Fifth Edition (CELF-5; Wiig et al., 2013) 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 at above chance levels (i.e., .50) in the No Variability condition ($M = .74$, $SD = .21$, range = .20–1.00), $t(70) = 9.45$, $p < .001$, $d = 1.12$, Multiple Exemplar condition ($M = .69$, $SD = 0.23$, range = .20–1.00), $t(70) = 6.91$, $p < .001$, $d = 0.82$, Multiple Speaker condition ($M = .74$, $SD = .18$, range = .30–1.00), $t(69) = 10.71$, $p < .001$, $d = 1.28$, and Combined

Cue condition (M = .67, SD = .26, range = .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 = .17, SE = .30, z = 0.55, p = .58). In addition, word learning performance in the Multiple Speaker condition (B = −.20, SE = .19, z = −1.04, p = .30) and Multiple Exemplar condition (B = −.30, SE = .23, z = −1.32, p = .19) was not significantly different from word learning performance in the No Variability condition (Fig. 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 = .88, SE = .35, z = 2.47, p < .05; OR (odds ratio) = 2.40, *95% CI* (confidence interval) = 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 with the Combined Cue condition (B = −.95, SE = .38, z = −2.47, p < .05; OR = 0.39, *95% CI* = 0.18–0.82) (Fig. 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 = .90, SE = .38, z = 2.39, p < .05; OR = 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; OR = 1.05, *95% CI* = 0.56–1.97).

In addition, 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 = −.22, SE = .008, z = −2.93, p < .01; OR = 0.98, *95% CI* = 0.96–0.99). In other words, each additional increase of 1 month in English age of acquisition was associated with a 2% decrease in the odds of selecting the correct word–object pair at test. See Table 5 for full model results of the simple effects analyses.

Discussion

In the current 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 with 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 with 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 current study, bilingual children

Table 3
Accuracy by language group and condition: Means (and standard errors).

Condition	Monolinguals	Bilinguals
No Variability	.73 (.04)	.75 (.04)
Multiple Speaker	.73 (.03)	.74 (.03)
Multiple Exemplar	.73 (.04)	.66 (.04)
Combined Cue	.62 (.05)	.72 (.04)

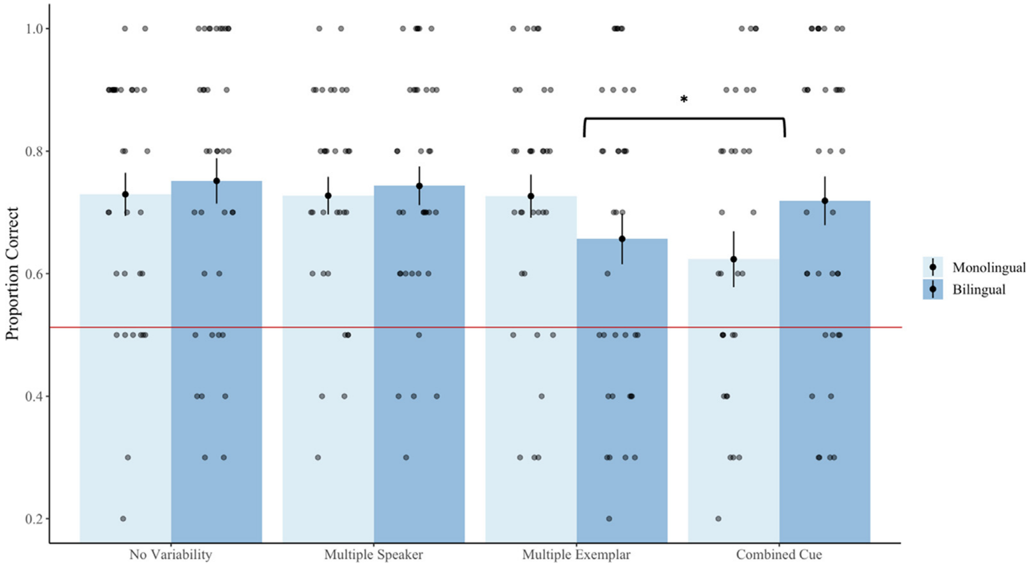

Fig. 1. Bar graphs depicting performance in monolinguals and bilinguals by condition. Error bars denote standard errors. Horizontal red line depicts chance levels (i.e., .50). Means and standard errors are reported in each bar. *p < .05.

Table 4
Full model results.

Condition:	Model 1[a]		Model 2[b]	
	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	−.20 (.19)	−1.04	.19 (.25)	0.74
Contrast 2	−.30 (.23)	−1.32	.03 (.20)	0.14
Group	.17 (.30)	0.55	.88 (.35)	2.47*
English age of acquisition	–	–	−.02 (.01)	−2.93**
Contrast 1 × Group	−.07 (0.36)	−0.20	−.49 (.42)	−1.19
Contrast 2 × Group	−.54 (0.35)	−1.53	−.95 (.38)	−2.47*
Observations	2120		2120	
Marginal R^2/Conditional R^2	.01/.23		.03/.26	

[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))).
* p < .05.
** p < .01.
*** p < .001.

were no more adept than monolingual children at learning word–referent mappings when performance in the Multiple Exemplar and Multiple Speaker conditions was compared with that in the No Variability condition. The results are consistent with the small number of studies suggesting that bilingualism might not modulate core XSWL abilities (i.e., one-to-one word–referent mappings) (e.g., Benitez et al., 2016; Poepsel & Weiss, 2016). Our results contribute to this growing literature and indicate that bilingual language experience might not influence how children map one-to-one

Table 5
Simple effects full model results.

Condition:	Model 1[a] Multiple Exemplar				Model 2[b] Combined Cue			
	B (*SE*)	*z*	*OR*	*95% CI*	*B* (*SE*)	*z*	*OR*	*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	.05 (.32)	0.17	1.05	0.56–1.97	.90 (.38)	2.39*	2.46	1.17–5.13
English age of acquisition	−.03 (.01)	−2.94**	0.97	0.95–0.99	−.03 (.01)	−2.01*	0.97	0.95–1.00
Observations	710				710			
Marginal R^2/Conditional R^2	.04/.26				.04/.32			

Note. OR, odds ratio; *CI,* confidence interval.
[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 were removed to resolve singularity and convergence issues.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

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., 2018; 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 (a) they were (a) smaller than in the combined condition and thus not detected or (b) 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; Kaushanskaya & 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 versus 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 Nicholas et al., (2019), while having little effect on bilingual word learning. Indeed, performance averages were relatively stable across conditions for bilinguals, whereas performance decreased when the input varied in two dimensions for monolinguals. 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 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 current 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 & Gentner, 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) might not extend to experimental statistical learning paradigms. However, facilitative effects of exemplar variability were plausible given recent evidence showing that children aged 7 to 9 years are sensitive to feature regularities that define visual objects (Broedelet et al., 2022). In this study, Broedelet and colleagues (2022) showed that children rely on the distribution of such regularities to build novel object categories. Therefore, null effects of exemplar variability in the current study may have been a product of our specific variability manipulation. Accommodating covariations 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 (e.g., 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 1 speaker and 10 different speakers. Crespo and Kaushanskaya (2021) observed a similar null finding of speaker variability, suggesting that the process of disambiguating word–referent mappings might 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 had been 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., Bent & Holt, 2013; Bradlow & Bent, 2008) 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

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 affect XSWL performance. However, compared with monolingual children, bilingual children were more likely to learn word–referent associations 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.

Data availability

I have shared a link to the data and scripts in the body of the manuscript.

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Data availability

Data and r-scripts are available at https://www.openicpsr.org/openicpsr/project/172882/version/V1/view.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105621.

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