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Word learning in the lab is hard! Data from 14-month-old monolingual and bilingual infants

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Abstract: Infants can learn words in their daily interactions early in life, and many studies have demonstrated that they can also learn words from brief in-lab exposures. While most studies have included monolingual infants, less is known about bilingual infants' word learning and the role that language familiarity plays in this ability. In this study we examined word learning in a large sample (up to $N = 155$) of bilingual and monolingual 14-month-olds using a preferential looking paradigm. To support word learning, novel words were presented within sentence frames in one language (single-language condition) or two languages (dual-language condition). We predicted that infants would exhibit greater word-object learning when they were more familiar with the language of the sentence frame. Using both traditional (t -tests) and updated (linear mixed-effects models) analyses, we found no evidence for successful word learning, nor an effect of familiarity. Our results suggest that word learning in experimental settings can be challenging for 14-month-olds, even when sentence frames are provided. We discuss these results in relation to prior work and suggest how open science practices can contribute to more reliable findings about early word learning.

Keywords: word learning; infants; bilingualism; open science.

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Introduction

Word learning is a complex process that begins to unfold over the first two years of life. Past research, using a variety of experimental designs, has provided important insights into word learning in both monolingual and bilingual infants (e.g., Fennell & Byers-Heinlein, 2014; Graf Estes, 2014; Mattock et al., 2010; Singh et al., 2018; Werker et al., 1998; Woodward et al., 1994). However, a new understanding of research best practices highlights the limitations of our traditional methodological and statistical approaches (Bergmann et al., 2018; Oakes, 2017). In this manuscript, we present a case study using traditional and more sensitive analytic techniques to examine the challenge of word learning in the lab with a large sample of 14-month-old monolinguals and bilinguals ($N = 155$). Following prior research (Fennell & Byers-Heinlein, 2014; Fennell & Waxman, 2010), we presented infants with novel words embedded into sentence frames, and then tested their learning in a looking time paradigm. We discuss whether infants of this age were able to learn new words in this context, and how our traditional research practices in early language acquisition can be improved to produce more reliable and reproducible findings.

Researchers have used experimental tasks to study word learning for more than 40 years (e.g., Carey & Bartlett, 1978). Dozens of studies have shown that infants and children can learn new words in the lab (Dal Ben et al., 2019; Tsui et al., 2019). They have also shown that infants' ability to make initial mappings between words and their referents, as well as their ability to retain these mappings, is affected by multiple factors related to the nature of the word learning task, including the particular stimuli used and how the words are encountered (Hirsh-Pasek et al., 2000; Kucker et al., 2015; McMurray et al., 2012; Werker & Curtin, 2005), as well as individual experience (e.g., language background; Tsui et al., 2019). Word learning skills also seem to improve with age (Frank et al., in press). As early as 6 months old, everyday language experience supports infants' ability to associate labels with referents such as food and body parts (Bergelson & Swingley, 2012), and at this age there is also evidence that infants can learn new words in the lab (Shukla et al., 2011). Some have argued, however, that there is a qualitative change in infants' word comprehension abilities that occurs just after their first birthday (Bergelson, 2020). Indeed, there are many more reports of infants aged 12 months and older showing successful word learning in the lab than reports of younger children. Our study tested infants at an age where basic laboratory word learning is thought to be relatively robust: 14 months.

Successful word learning in the lab has been reported in different contexts. For example, Woodward et al. (1994) found that 13-month-old monolingual infants mapped a novel word to its referent after only nine encounters with the word-referent pair presented by a live experimenter. More recently, Chen and colleagues (2020) used a similar paradigm and found that monolingual 20-month-olds could learn a native and a foreign word after only 6 encounters with the word-referent pair. Lab studies using more stripped-down tasks (i.e., without live social interaction) have also shown successful word learning. For instance, 15-month-olds learned two novel words in a preferential looking paradigm where isolated novel words (e.g., "*bard*") and pictures of novel objects were paired, with no social agents or social support (Schafer & Plunkett, 1998). In addition, using the Switch

task, wherein infants are habituated to two novel word–object pairings and then presented with a mismatch at test, similar results were found with 14-month-old monolinguals (Werker et al., 1998) and bilinguals (Byers-Heinlein et al., 2013).

For slightly older monolingual (15-month-olds, Fennell & Waxman, 2010) and bilingual (17-month-olds, Fennell & Byers-Heinlein, 2014) infants, sentence frames have been shown to enhance word learning and recognition. For instance, monolingual 18-month-olds showed faster recognition of familiar words presented in sentence frames than in isolation (Fernald & Hurtado, 2006). Moreover, while 14-month-olds often find minimal pair word learning challenging (Stager & Werker, 1997), monolingual 14-month-olds successfully mapped minimal pairs (*bin* and *din*) to objects during the Switch task when the words were embedded in sentence frames (Fennell & Waxman, 2010). Similarly, 16-month-old bilinguals, whose languages shared linguistic similarities (e.g., French and Spanish), mapped minimal pairs (*koet* and *goet*) to objects when words were embedded in sentence frames and presented in a live interaction experiment (Havy et al., 2016). Seventeen-month-old monolinguals and French–English bilinguals also learned minimal pair labels (*kem* and *gem*) embedded into sentences that were produced by a speaker that matched their language background (Fennell & Byers-Heinlein, 2014). Sentence frames may support word learning by providing familiar linguistic context, highlighting the referential nature of the word learning task, and decreasing infants' cognitive load. This information might be particularly useful for bilingual infants, who may use sentential frames to determine which language a word belongs to (Fennell & Byers-Heinlein, 2014; Fernald & Hurtado, 2006; Havy et al., 2016).

The current study extended previous research by investigating word learning just after infants' first birthdays. We asked if 14-month-old monolinguals and bilinguals would successfully learn new words embedded in sentence frames. Moreover, we were interested in the role of infants' language background, specifically whether they were growing up in a monolingual or a bilingual environment. Despite deploying similar mechanisms for word learning (Byers-Heinlein et al., 2013; Byers-Heinlein & Werker, 2009; Kandhadai et al., 2017), infants growing up bilingual face challenges that may impact their language development (Fennell et al., 2007; Graf Estes & Hay, 2015). For instance, bilingual infants often hear interlocutors alternate between two languages in the same contexts (Place & Hoff, 2011), especially when bilingual parents teach new words (Byers-Heinlein, 2013; Kremin et al., 2020). In addition, unlike monolinguals who generally need to associate one basic-level label to each referent they encounter, bilinguals must learn at least two labels, one in each of their languages (Byers-Heinlein, 2017; Kandhadai et al., 2017).

Our paradigm presented monolingual and bilingual infants with novel words embedded in sentence frames that had varying degrees of linguistic familiarity. Specifically, we presented 14-month-olds pictures of novel objects paired with the dissimilar-sounding novel words “*kem*” and “*bos*” embedded in English and/or French sentence frames. Our study had two training conditions. In the single-language condition, both words were presented in the same language (either in English or in French sentence frames), and in the dual-language condition each word was presented in a different language (one in English sentence frames and one in French sentence frames). After training, infants were tested in a

preferential looking paradigm, where they saw both novel objects side-by-side and heard one of the words in isolation. Infants came from one of three backgrounds: (a) monolingual English *or* French, (b) bilingual English *and* French, or (c) bilingual English or French and another language. That is, all infants had exposure to one or both of the sentence frame languages (English and French), but to varying degrees, as bilingual infants are rarely perfectly balanced in their exposure to each of their languages (i.e., they typically have a dominant and a non-dominant language; Byers-Heinlein et al., 2019). By including infants from these diverse language backgrounds, we could examine the effect of bilingualism as well as its interaction with infants' familiarity with the sentence frame languages. We hypothesized that infants would show better word learning on trials where the sentence frame language was more familiar, so for example better performance in bilingual infants' dominant over their non-dominant language.

The combination of different language backgrounds and conditions was originally conceptualized as forming a set of 7 different experiments (see Table 1). Following past studies, we had planned a sample size of 16 infants per experiment (see Oakes, 2017, for evidence that this sample size is typical of many infant experiments, although a recent meta-analysis has revealed that this often yields underpowered experiments; Bergmann et al., 2018). However, after 7 years of data collection (2012–2019), and despite collecting data from 288 infants (many of whom ultimately had to be excluded from analyses, discussed further below), we were not able to achieve our target sample for all experiments, and thus chose to terminate data collection. We note that by this point the last author of this paper (the Principal Investigator) was the only researcher still in the lab from the time the experiment began. A subset of these data from monolingual infants—who were substantially easier to recruit—was published by da Estrela and Byers-Heinlein (2016), who designed the experimental approach and created the stimuli. They reported an experiment under which monolinguals learned the novel words, as well as two experiments in which they failed to learn. In retrospect, we note that all of the studies reported back then were underpowered, which could lead to spurious findings (Oakes, 2017). We expand on this point in the Discussion.

Table 1. Examples of Infants' Familiarity with Sentence Frame Languages

Language Group	Experiment Number	Language Background	Infant's Most Familiar Language (e.g., English; <i>Look! It's the Bos!</i>)	Infant's Least Familiar Language (e.g., French; <i>Regarde! C'est le Kem!</i>)
Dual-Language Condition				
Bilinguals	1	L1 English L2 French	Dominant	Non-Dominant
	2	L1 English L2 Other	Dominant	Foreign
	3	L1 Other L2 English	Non-Dominant	Foreign
Monolinguals ^b	4	L1 English	Dominant/Native	Foreign
Single-Language Condition ^a				
Bilinguals	5	L1 English L2 French	Dominant	NA
Monolinguals	6	L1 English	Dominant/Native	NA

Monolinguals ^b	7	L1 French	NA	Foreign
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Note. In these examples English is the most familiar language and French is the least familiar language. The relationships are reversed when French is the most familiar language. L1 = Infants' dominant (or native in the case of monolinguals) language; L2 = Infants' non-dominant language.

The experiments presented here were conceptualized before new approaches (e.g., large-scale collaborations; ManyBabies Consortium, 2020) and articles calling for better research practices were widely disseminated in the field of developmental psychology (Bergmann et al., 2018; Bishop, 2020; Oakes, 2017; Schott et al., 2019), although such ideas were being discussed in some other fields (Button et al., 2013; Ioannidis, 2005; John et al., 2012; Simmons et al., 2011). However, for different reasons, most notably the slow pace of infant data collection (especially with bilingual infants), we found ourselves analyzing our data after improved research practices were becoming more common in infant research and the field of bilingualism. This laid bare some problematic characteristics of our original approach, which would likely have characterized many published studies in the field: it was not pre-registered; it had small sample sizes per experimental group; planned statistical analyses focused on small individual experiments rather than the dataset as a whole; there was potential for undisclosed flexibility in the analysis; and monolingualism and bilingualism were defined categorically in a way that ultimately excluded many participants who were tested (see Byers-Heinlein, 2015; Kremin & Byers-Heinlein, 2020; Luk, 2015; Luk & Bialystok, 2013, for a longer discussion of categorical versus continuous approaches to bilingualism).

Our conundrum raises an important question for studies with a long gap between study planning and data analysis: when should researchers stick with their original plan that is consistent with the rest of the literature, and when should they use updated approaches such as combined analyses that yield larger sample sizes, advanced statistical methods, and open science practices? We have ultimately decided to take both paths at once, in order to better understand how we should conceptualize older versus newer research practices in the context of the literature on infant word learning. In what follows, we first present our planned analysis (which we refer to as the traditional approach) and then a re-analysis of our data using a more sensitive technique (which we refer to as the updated approach). Finally, we discuss how the use of traditional versus updated approaches can affect our conclusions about an infant experimental word learning task, contributing to the discussion on how to improve practices in infant research.

Given the bulk of evidence from the published literature that 14-month-old monolinguals and bilinguals can successfully learn new words in the lab, we expected that at least under some conditions, infants would also be successful in our task. More specifically, we expected that the more familiar infants were with the language of the sentence frame, the better they would learn the novel words. For instance, we expected that word learning would be easier for bilingual infants when they heard the sentence frame in their dominant rather than in their non-dominant language, and infants should have the most difficulty learning a new word embedded in foreign language sentence frames (e.g., an English monolingual infant hearing a French sentence). We also explored whether infants would show better learning as a function of how many words they knew in the sentence frame language, and whether attention during the Training phase contributed to successful word learning.

Method

Participants

A total of 288 infants were tested between August 2012 and July 2019. Following standard practice in our lab, we excluded infants born premature (i.e., < 37 weeks of gestation, $n = 10$), with low birth weight (i.e., < 2500 grams, $n = 11$), with reported major health issues ($n = 1$), and those who were inattentive or too fussy to complete the study ($n = 44$). We also excluded infants due to technical problems ($n = 17$), experimenter error ($n = 4$), parental interference during the experimental portion of the study ($n = 2$), bilingual infants who were not exposed to both languages from birth ($n = 24$), and those without enough data obtained from testing trials ($n = 7$; see Results section for a full explanation of these criteria). For the traditional analysis, we also excluded bilingual infants who did not meet the study's language criteria (i.e., exposure to a second language did not reach at least 25%, or children were regularly exposed to 3 languages; $n = 45$) or who did not have at least one valid testing trial per target word (i.e., at least one testing trial for “*kem*” and one for “*bos*”, $n = 13$). However, we included these infants in our updated analytical approach, as it has the ability to handle missing data and to treat language exposure as a continuous variable. We return to the issue of this steep reduction of sample size due to exclusions in the Discussion.

This study was conducted in Montreal, a multicultural city where a high proportion of children are raised in a bilingual environment (Schott et al., 2019). The final sample for the traditional analysis included 110 14-month-olds (age range: 13 months and 16 days – 15 months and 12 days) from diverse language backgrounds. The sample included 28 monolingual infants who participated in a prior study (infants from Experiment 1 and Experiment 2 from da Estrela and Byers-Heinlein (2016), whose data were re-analyzed). Monolingual infants ($n = 50$, including re-analyzed data) were exposed to one language, either English or French, 90% of the time or more. Bilingual infants were exposed to at least 25% of the time to each of two languages, and less than 20% to a third language. We included bilingual infants exposed to English *and* French ($n = 36$) and bilingual infants exposed to English *or* French and another language ($n = 24$). Bilingual infants in all studies were exposed to at least one of the sentence frame languages (English and French) since birth. Data on age of acquisition were missing for three bilinguals. Participants' demographic characteristics are presented in Table 2.

The final sample for the updated analysis consisted of 155 infants, a 41% increase in sample size compared to the traditional analysis. This included all infants from the traditional analyses ($n = 110$), plus 30 infants whose language exposures fell outside the criteria established for bilingualism and monolingualism in the traditional approach, as well as 15 infants who had been excluded from the Traditional analysis for not having at least one valid Test trial per novel word.

Table 2. Infant Demographic Characteristics by Language Group

Language Group	<i>n</i>	Mean Age in Months (<i>SD</i>)	Age Range	Sex	Language Dominance	% Language Exposure
Traditional Analysis						
Monolingual	50	14m 13d (13.3d)	13m 17d– 15m 7d	48% female	24 English native 26 French native	98.3% English (English Monolinguals) 98.4% French (French monolinguals)
Bilingual English– French	36	14m 14d (14.8d)	13m 16d– 15m 12d	58% female	19 English dominant 17 French dominant	66.1% English and 32.6% French (English-dominant bilinguals) 61.8% French and 37.0% English (French-dominant bilinguals)
Bilingual English or French & Other Lan- guage	24	14m 6d (11.1d)	13m 24d– 14m 29d	58% female	5 English dominant 5 French dominant 14 dominant in another lan- guage (of these, 6 had English and 8 had French as their non- dominant language)	64.3% English and 35.7% other language (English-dominant bilinguals) 61% French and 39% other language (French-dominant bilinguals)

64% Other language and 35.8% English/French (Other language-dominant bilinguals)

Additional infants included in the updated analysis

Other (e.g., trilinguals, bilinguals with minimal second language exposure)	45	14m 4d (13.7d)	13m 7d– 15m 4d	53% female	60% were more dominant in English	NA ^a
					28% were more dominant in French	
					11% were dominant in another language (of these, 3 had English and 2 had French as their non-dominant language)	

Note. *M* = mean; *SD* = Standard Deviation, m = months, d = days. The percentage of language exposure does not add to 100% in some cases, since some infants in monolingual or bilingual groups had a small amount of exposure to other languages.

^aFor additional infants included in the updated analysis, language exposure is measured continuously, thus infants are not assigned to language groups and therefore a meaningful summary statistic for language exposure cannot be calculated for this group

Stimuli

We used the same stimuli and general procedure as da Estrela & Byers-Heinlein (2016). The visual stimuli had been used in prior research examining word learning in monolingual and bilingual infants (Byers-Heinlein et al., 2013; Curtin et al., 2009; Fennell & Waxman, 2010). The auditory stimuli were recorded in our lab and were previously used in an experiment on word learning with monolingual infants (da Estrela & Byers-Heinlein, 2016).

Visual stimuli consisted of two novel objects: a crown shape and a molecule shape (Figure 1). Auditory stimuli consisted of the target words /bos/ and /kɛm/, which were presented embedded in English and/or French sentence frames (Training) or in isolation (Test). Across experimental conditions the molecule shape was always presented with the novel word *kem* and the crown shape was always presented with the novel word *bos*. The target words were phonetically possible in English and French. Identical tokens for the target words were used across all conditions, which was accomplished through cross-splicing tokens that were ambiguous in language (i.e., were pronounced in a way that was neither distinctly English nor distinctly French) into both English and French sentences. There were 3 sentence frames used in English ("Look, it's the ____!"... "Do you see the ____?"... "I like the ____!") and 3 in French ("Regarde, c'est le ____!"... "Vois-tu le ____?"... "J'aime le ____!"). The novel words (i.e., /bos/ and /kɛm/) were always presented in a sentence-final position to increase their salience (Echols & Newport, 1992; Fernald & Hurtado, 2006). Sentences were matched on length and prosody to minimize differences across the stimuli, and were selected to ensure that the stimuli sounded as natural as possible. All stimuli were recorded by a native bilingual English–French female using infant-directed speech.

Auditory and visual stimuli were combined into videos to create Training and Test trials. Training trials consisted of the presentation of the target object looming against a black background. The visual stimulus appeared 1.5 seconds before the presentation of the sentence frame. Three sentences were presented during each Training trial (e.g., "Look, it's the kem!"... "Do you see the kem?"... "I like the kem!"), with an interval of 1.5 seconds of silence between them. The duration of each Training trial was approximately 11 seconds. Test trials consisted of the presentation of an isolated word repeated three times (e.g., "Kem!"... "Kem!"... "Kem!"), along with both novel objects side by side (i.e., the crown-shaped and molecule-shaped objects). There were four Test trials (i.e., two for each novel word), each lasting approximately 10 seconds. Test trials were identical across conditions. Stimuli are available at <https://osf.io/g6nrv>. Figure 1 shows the stimuli and timeline during an example Training and an example Test trial.

Training

Example training trials for the dual-language condition (16 trials total)

Test

Example test trials for the dual-language condition (4 trials total)

Figure 1. Examples of the trial sequence for the Training and Test phases of the dual-language condition. The single-language condition was identical except all carrier phrases were in the same language. Training trials were 11 seconds long and consisted of a looming visual stimulus of a novel object that was present for the entire trial. For the first 1.5 seconds the image appeared in silence, followed by 8 seconds where it was accompanied by an auditory stimulus with the target novel word embedded in either a French or English sentence, followed once again by 1.5 seconds of silence. Test trials were 10 seconds long, and consisted of both novel objects side by side, present for the entire trial. The images appeared in silence for 3 seconds, followed by 5.5 seconds where they were accompanied by an auditory stimulus repeating the target word 3 times, followed once again by the images alone for the final 1.5 seconds.

Design

Two experimental conditions were developed for the current study: a single-language condition and a dual-language condition. In the single-language condition both objects were labeled in the same language (either English or French) during Training. In the dual-language condition, one object was labeled in English and the other object was labeled in French during Training. Regardless of condition, each object was labeled 3 times each across 8 trials for a total of 24 labeling events per object. Infants thus encountered a total of 16 Training trials, presented in one of 8 pseudo-random orders with the constraint that

the same word was not encountered for more than two consecutive trials. Orders counterbalanced which word was encountered first, and for the dual-language condition, the pairing of word and language (e.g., whether *bos* was presented in English versus French sentences).

The Test phase for all orders and both conditions presented the words *kem* and *bos* in an alternating fashion—never repeating a word or the side the image appeared on twice in a row. This was to avoid infants developing a side strategy (e.g., if the target appeared on the right twice in a row, infants could anticipate that on the third Test trial the target would yet again appear on the right). Test trials were counterbalanced such that for every order where the Training phase ended with *kem*, the corresponding Test phase started with *bos*, and vice-versa (for test orders see <https://osf.io/g6nrv>).

Infants participated in one of 7 different experiments (see Table 1), defined by the experimental condition they completed (single-language versus dual-language) and their own language background. Based on these two factors, we coded a derived variable called *familiarity*, which related to infants' exposure to the sentence frame language and had two possible values: most familiar and least familiar. Note that this variable describes familiarity with the sentence frame languages only—a trial coded as most familiar means the most familiar of English and French, not necessarily an infant's most familiar language overall. This variable was primarily descriptive for the traditional analysis.

In the dual-language condition (Experiments 1–4), infants encountered one word in English sentence frames and the other in French sentence frames. Recall that all infants we tested had regular exposure to English and/or French. French–English bilinguals were familiar with both languages, so the word encountered in their dominant language was coded as most familiar, and the one encountered in their non-dominant language was coded as least familiar (Experiment 1). Bilinguals exposed to English or French and another language were also familiar with one of the sentence frame languages (either English or French, but not both); in some cases the most familiar sentence frame language was the infants' dominant language (Experiment 2), and in other cases it was the infants' non-dominant language (Experiment 3). As monolinguals were familiar with only one of the sentence frame languages, this language was coded as most familiar (Experiment 4).

In the single-language condition (Experiments 5–7), both novel words were encountered in the same sentence frame language, thus all trials had the same level of familiarity to each infant. The bilinguals tested in the single-language condition were all French–English bilinguals and were purposefully tested with stimuli in their dominant language, thus all sentence frames were coded as most familiar (Experiment 5). Familiarity was coded as most familiar for monolinguals tested with native language sentence frames (Experiment 6), and least familiar for monolinguals tested with sentence frames in the other language (which was foreign to them; Experiment 7).

Under the updated analytic approach, we included percent of exposure to the sentence frame language as a continuous version of this categorical familiarity variable. For exam-

ple, on trials where the novel word was presented in an English sentence frame, an English monolingual would have an exposure score of 100, a French monolingual 0, a French–English bilingual 25 (as one possible value, if they were exposed to English 25% of the time), and a French–Arabic bilingual 0. Thus, higher exposure scores indicate more familiarity with the sentence frame language.

Procedure

A research assistant greeted the parents and explained the main purpose of the study and the general procedure. Parents then signed the consent form and filled out three questionnaires. The first questionnaire gathered basic demographic information (i.e., infants' general health, birth weight, weeks of gestation and socioeconomic status of the family). The second questionnaire was a detailed interview about the infant's language background starting from birth, using the Language Exposure Questionnaire (LEQ; Bosch & Sebastián-Gallés, 2001) with the Multilingual Approach to Parent Language Estimates (MAPLE; Byers-Heinlein et al., 2019). The third questionnaire (the MacArthur-Bates Communicative Development Inventories: Words and Gestures; Fenson et al., 2007) gathered data on the infant's vocabulary knowledge.

After the questionnaires were filled out, the infant and parent were brought to a sound-attenuated room. The infant sat on the parent's lap in a chair approximately 60 cm away from a Tobii T60 XL eye-tracker, which recorded participants' gaze at 60 Hz. Tobii Studio software was used to display the stimuli on a 24" monitor. Parents were given darkened glasses and headphones playing music, and were instructed not to interact with the child to avoid influencing the infant's responses. Following a 5-point eye-tracking calibration, the experiment started with a 10-second pre-familiarization trial, which consisted of a spinning pinwheel accompanied by a sound. Next, infants saw 16 Training trials (8 for *kem* and 8 for *bos*), and 4 Test trials (2 for *bos* and 2 for *kem*). Between each trial, infants saw an attention-getter (a circle stretching vertically and then horizontally while changing colors) to direct their attention back towards the screen. The experiment ended with the presentation of the spinning pinwheel, and in total lasted approximately 5 minutes.

Analytic Approaches

We report two analytic approaches. In the traditional analysis, we used single-sample, two-tailed *t*-tests against chance (.5) to test word learning for each experiment in each condition, following da Estrela & Byers-Heinlein (2016). In the updated analysis, we analyzed all experiments in aggregate, using mixed-effects models. Both analyses were performed using R (R Core Team, 2020). Mixed-effects models were fitted using the lme4 package (Bates et al., 2015). All data and scripts are available at <https://osf.io/upy7f>. It is worth noting that in da Estrela & Byers-Heinlein's (2016) previously published study, data had been tabulated by hand using Excel, and analyzed using the proprietary statistical software SPSS, which restricted the study's reproducibility and limited access to the analyses. In addition to being openly available and easily reproducible, R also provides powerful functions for data cleaning and organization. For instance, by developing a fully

reproducible analysis pipeline in R, we found that 4 participants had been incorrectly included in the previously published experiment despite not meeting the specified inclusion criteria (da Estrela & Byers-Heinlein, 2016). These were excluded in the present analyses. Another 2 infants had a data-entry error, which we corrected.

Results

Traditional Analysis

The original study's design included 7 experiments (Table 1) that varied according to the experimental condition (i.e., single-language or dual-language), the infant's language background (i.e., monolingual, bilingual English–French, bilingual English/French and another language), and by familiarity with the sentence frame languages they were tested in (i.e., whether the word was encountered in the most familiar or least familiar language).

For the dual-language condition (Experiments 1, 2, 3 and 4), we conducted a preliminary series of paired sample *t*-tests to see if infants preferred the most familiar sentence frame language over the other during Training (Table 3). This was to ensure that any differences at Test would not be due to differential attention during Training. We found no statistically significant differences between groups. However, we found a medium-to-large effect size (Cohen's $d = -.64$) for bilingual infants dominant in French or English with another second language, who looked longer to Training trials in their most familiar language. Given that this was only observed in one of the seven studies and was not statistically significant (even prior to correction for multiple comparisons), this effect is unlikely to be meaningful.

To examine whether infants showed learning of the novel words, we conducted a series of *t*-tests on data from the Test phase, comparing the proportion looking time to the target object against chance (.5). Following da Estrela and Byers-Heinlein (2016), only infants with at least one data point for each word (i.e., one for *kem* and one for *bos*) were included in the analyses. Only the monolingual infants in the dual-language condition (Experiment 4) looked at the correct object above chance, but only when the novel word was presented in a foreign sentence frame during Training ($M = .67$, $SD = .22$), $t(17) = 3.16$, $p = .006$, $d = .75$ (Figures 2 and 3; Table 4). This result was surprising. We expected this to be the most challenging context for word learning, given that infants were completely unfamiliar with the sentence frame language. Again, it is plausible that this result is spurious.

Table 3. Total Looking Time in Seconds during Training in the Dual-Language Condition

Language Group	Experiment Number	Most Familiar Language Mean (<i>SD</i>)	Least Familiar Language Mean (<i>SD</i>)	<i>t</i> -test
Bilingual French/English (<i>n</i> = 17)	1	40.16 (20.91)	41.25 (15.96)	$t(16) = .43, p = .673, d = .10$
Bilingual Dominant in English/French and L2 Other (<i>n</i> = 10)	2	51.14 (12.67)	42.44 (14.22)	$t(9) = -2.02, p = .074, d = -.64$
Bilingual Dominant in Other Language and L2 English/French (<i>n</i> = 14)	3	48.23 (16.35)	46.75 (16.03)	$t(13) = -.71, p = .490, d = -.19$
Monolingual (<i>n</i> = 18)	4	32.65 (20.25)	31.69 (17.41)	$t(17) = -.34, p = .739, d = -.08$

Note. L2 refers to infants' non-dominant languages.

Table 4. *t*-test Results and Proportion of Looking Time by Group and Condition for the Traditional Analytic Approach

Language Group	<i>n</i>	Sex	Experiment Number	Familiarity	Mean	SD	<i>t</i>	<i>p</i>	<i>df</i>	<i>d</i>
Dual-Language Condition										
Bilingual English-French	17	8 females	1	Most Familiar (Dominant)	.59	.20	1.84	.085	16	.45
				Least Familiar (Non-Dominant)	.50	.12	-.05	.965	16	-.01
Bilingual Dominant in English-French and L2 other language	10	6 females	2	Most Familiar (Dominant)	.53	.17	.49	.637	9	.16
				Least Familiar (Foreign)	.48	.21	-.25	.805	9	-.08
Bilingual Dominant in other language and L2 English or French	14	8 females	3	Most Familiar (Non-Dominant)	.50	.16	-.10	.926	13	-.03
				Least Familiar (Foreign)	.48	.22	-.35	.734	13	-.09
Monolingual	18	8 females	4	Most Familiar (Native)	.54	.23	.75	.467	17	.18

					Least Familiar (Foreign)	.67	.22	3.16	.006*	17	.75
Single-Language Condition											
Bilingual English– French	19	13 fe- males	5	Most Familiar (Dominant)	.54	.22	1.18	.253		18	.27
Monolingual	16	9 females	6	Most Familiar (Native)	.52	.24	.46	.652		15	.12
Monolingual	16	7 females	7	Least Familiar (Foreign)	.55	.24	1.86	.082		15	.47

Figure 2. Bar graphs showing proportion looking to the correct object by group in the dual-language condition and standard errors. Same-colour bars represent an experimental language group. The teal bars represent Experiment 1 (English–French bilinguals). The yellow bars represent Experiment 2 (bilinguals whose first language is English or French with a second language that is not English or French). The blue bars represent Experiment 3 (bilinguals whose first language is not English or French with English or French as their second language). The red bars represent Experiment 4 (English or French monolinguals). Data are faceted by infants' familiarity with the sentence frame language. ** $p < .01$

Figure 3. Bar graphs showing proportion looking to the correct object by group in the single-language condition. The purple bar represents Experiment 5 (English–French bilinguals), the orange bar represents Experiment 6 (English or French monolinguals tested in their native language), and the green bar represents Experiment 7 (English or French monolinguals tested in the language they do not know). Data are faceted by infants' familiarity with each sentence frame language.

Updated Analysis

Our traditional analysis tested the performance of small groups of participants against chance level, following the relevant literature at the time the study was designed. More recent discussions on the reproducibility and reliability of psychological science highlight the need for more sensitive analytical approaches that take into consideration the structure of the data (e.g., repeated measures) and that have an appropriate sample size (Bergmann et al., 2018; Oakes, 2017). One well-accepted approach is mixed-effects models (Dixon, 2008). These models have several advantages over traditional methods such as ANOVAs or multiple *t*-tests on different groups. For instance, they can account for the relationship between continuous outcomes (e.g., looking time to the target) and continuous predictors (e.g., language exposure, vocabulary size), which are modeled as fixed effects. They can also account for systematic variability arising from data being grouped (e.g., repeated measures within participants or items), which are modeled as random effects. Furthermore, by modelling fine-grained data (e.g., trial-level data rather than condition averages), these models have greater statistical power and better handling of missing data, even for unbalanced datasets (Baayen et al., 2008; Bates et al., 2015).

Here we used a larger, more inclusive sample ($N = 155$; see Participants for details). Although larger, we must note that this sample was highly heterogeneous, with infants from diverse linguistic backgrounds (Table 2). To harness the richness of our data, we fitted four linear mixed-effects models. The proportion of looking time to the labeled object minus the chance level (.5) was the dependent variable in all four models. We subtracted the chance level so that the intercept would capture overall word learning different from chance. First we fit an intercept-only model to examine infants' mean accuracy before exploring potential moderators of performance (Table 5). The next three models explored the effects of three variables on learning: the percent of exposure to the sentence frame language (Table 6), infants' receptive vocabulary size (comprehension) in the sentence frame language (Table 7), and the total looking time to the objects during the Training phase (Tables 8). These were entered as continuous predictors into three separate models. Percent of exposure to the sentence frame language and vocabulary size in the sentence frame language allowed us to further explore if or how our participants' language background guided learning. Total looking time to the objects during Training allowed us to investigate if participants who were more or less attentive during Training would show differences in learning during the Test phase.

The random effects structure was the same for all four models. We initially attempted to fit a maximal random effects structure: novel words (either *kem* or *bos*) as random slopes and participants as random intercepts (Barr et al., 2013). These models failed to converge. We then attempted to include the novel words and participants as random intercepts. Once again, the models failed to converge and a closer inspection indicated that there was not enough variability between participants to be included as random intercepts. Thus, we simplified the models to include only the target words as random intercepts. These models converged and respected the assumptions of normality (see <https://osf.io/up7f> for details).

The results from the models are displayed in Tables 5, 6, 7, 8, and Figure 4. Overall, our reanalysis with this more sensitive approach and the larger sample size confirmed the pattern found in the traditional analyses: there was no evidence of overall word learning, and further no significant relationships between the proportion of looking to the target and (a) exposure to the sentence frame languages, (b) receptive vocabulary size in the sentence frame languages, or (c) the total looking time to the objects during Training. All models produced an estimate of zero associated with the intercept as well as with our predictors. This means that none of our variables predicted the proportion of infants' looking at the labeled objects (Tables 6 to 8). Furthermore, our approximate effect size, calculated from the intercept-only model using Brysbaert & Stevens' (2018) approach, was very small ($d = 0.09$). All in all, we did not find evidence of word learning. Our models also provided little to no account of the observed variance.

Table 5. Fixed and Random Effects for the Intercept Only Model [proportion of looking time - .5 ~ 1 + (1 / target word)]

Predictors	Estimates	95% Confidence Interval	<i>p</i>
Intercept	0.02	-0.06 – 0.10	0.571
Random Effects			
σ^2	0.06		
τ_{00} target word	0.00		
ICC	0.04		
Observations	498		
Marginal R^2 / Conditional R^2	0.000 / 0.043		

Table 6. Fixed and Random Effects for the Pruned Model with Exposure to Sentence Frame Language as a Predictor of Looking to the Labeled Object [proportion of looking time - .5 ~ exposure + (1 | target word)]

Predictors	Estimates	95% Confidence Interval	<i>p</i>
Intercept	0.02	-0.06 – 0.10	0.654
Exposure to sentence frame language	0.00	-0.00 – 0.00	0.803
Random Effects			
σ^2	0.06		
τ_{00} target word	0.00		
ICC	0.04		
Observations	498		
Marginal R^2 / Conditional R^2	0.000 / 0.043		

Table 7. Fixed and Random Effects for the Pruned Model with Vocabulary Size (comprehension) in the Sentence Frame Language as a Predictor of Looking to the Labeled Object [proportion of looking time - .5 ~ vocabulary + (1 | target word)]

Predictors	Estimates	95% Confidence Interval	<i>p</i>
Intercept	0.01	-0.06 – 0.09	0.718
Receptive vocabulary for sentence frame language	0.00	-0.00 – 0.00	0.417
Random Effects			
σ^2	0.06		
τ_{00} target word	0.00		

ICC	0.04
Observations	498
Marginal R ² / Conditional R ²	0.001 / 0.043

Table 8. Fixed and Random Effects for the Pruned Model with Total Looking Time during Training as a Predictor of Looking to the Labeled Object [proportion of looking time - .5 ~ total looking time on Training + (1 / target word)]

Predictors	Estimates	95% Confidence Interval	<i>p</i>
Intercept	0.05	-0.04 – 0.14	0.286
Total looking time during Training	-0.00	-0.00 – 0.00	0.227
Random Effects			
σ^2	0.06		
τ_{00} target word	0.00		
ICC	0.05		
Observations	495		
Marginal R ² / Conditional R ²	0.003 / 0.048

Figure 4. *Proportion of looking at the correct object as a function of (A) percentage of exposure to the sentence frame languages, (B) vocabulary size (number of words comprehended) in the sentence frame languages, and (C) total looking time (ms) during the Training phase. Regression lines, standard errors, and the 498 data points entered in models A and B, and the 495 data points entered in model C are plotted. Note that chance is .5.*

Overall, these results provide a more sensitive and reliable confirmation that learning words in the lab can be challenging for 14-month-olds, regardless of language background, the familiarity of sentence frames, and overall attention during Training. We address some of the possible challenges in the Discussion.

General Discussion

The present study investigated word learning in 14-month-olds from different language backgrounds using a preferential looking paradigm. Following prior research (Fennell & Waxman, 2010; Fernald & Hurtado, 2006; Havy et al., 2016) we assumed that the use of sentence frames would support word learning in infants. Moreover, we predicted that language familiarity would play a key role in word learning, with infants showing better learning of word-object associations when they had greater familiarity with the sentence frame language. Neither traditional (*t*-tests) nor updated (linear mixed-effects models)

analyses indicated an effect of familiarity. Perhaps more surprising, we found very little evidence for successful word learning at all in this paradigm. Out of 7 *t*-tests conducted in our traditional analysis, only one showed performance that was statistically above chance, which we interpret as likely a false positive. Moreover, our updated analysis using the combined dataset, which had greater statistical power, found no evidence of word learning. Our results suggest that word learning in the lab can be challenging for young bilingual and monolingual infants, even with supporting sentence frames.

These findings are unexpected and contrast with previous studies that have reported successful word learning for monolingual 14-month-olds using isolated words (Werker et al., 1998) and sentence frames (da Estrela & Byers-Heinlein, 2016; Fennell & Waxman, 2010). Importantly, our task was designed to be easy and conducive to word learning. To this end, we used sentence frames which were meant to provide further linguistic cues and presented the target words in sentence-final position to increase their salience (e.g., Fennell & Byers-Heinlein, 2014; Fernald & Hurtado, 2006). In addition, each word was repeated multiple times during Training (3 times per trial for 8 trials, for a total of 24 exposures to each word–object pairing) and we taught infants only two novel words to reduce their cognitive load. Even so, neither monolingual nor bilingual infants appeared to learn even the word–object pairs presented in the sentence frame language that was most familiar to them.

Although our experiment was designed to provide a facilitative word learning opportunity for infants, it is possible that the task was simply too taxing. It might be that infants at this age need increased exposure to the target word during Training (more than the 24 total exposures in our study) in order to make word–referent associations. Relatedly, our study presented infants with a fixed number of Training trials rather than presenting Training trials according to a habituation criterion (as in the Switch task), which may make our task less effective as it did not adapt to each infant's learning. It could also be the case that infants required additional familiarization with the task structure (e.g., familiar-word trials presented before Training, where a known word is associated with a known object to cue the task). However, this interpretation contrasts with reports in the published literature. For example, Schafer and Plunkett (1998) reported successful word learning after 12 presentations of each of 2 novel word–referent pairs in 15-month-olds using a similar paradigm to that implemented in our study (though they also presented familiar-word trials between the novel word trials).

It is also possible that sentence frames made our task more challenging, contrary to our intentions. We used sentence frames following prior research with monolingual and bilingual infants showing that they have a facilitative effect (Fennell & Byers-Heinlein, 2014; Fennell & Waxman, 2010; Fernald & Hurtado, 2006). Thus, we expected that sentence frames would support word learning, particularly for bilingual infants, since this additional information might help them identify the language in which a novel word is presented. Yet, this did not appear to be the case. Future studies with bilingual infants could compare experimental conditions that vary on the use of isolated words versus sentence frames (e.g., Morini & Newman, 2019), to disentangle the effect that additional linguistic information has on early word learning.

Another possible explanation is that infants did successfully learn one or both words presented during Training trials, but our Test phase was not sufficiently sensitive to show this learning. It could be that the 4 Test trials included in our study (2 per novel word) were not enough to detect learning, especially because some infants did not provide valid data for both words during the Test phase. Increasing the number of Test trials per infant might increase the chances of capturing learning in this hard-to-test population, and would most likely generate a better representation of infants' true response to the task, thus decreasing noise and increasing statistical power (DeBolt et al., 2020).

Moreover, we selected the preferential looking task based on extant literature suggesting that it might be more sensitive to detect word learning than other paradigms such as the Switch task (Yoshida et al., 2009). However, many studies reporting successful word learning in infants have used the Switch task (see Tsui et al., 2019 for a meta-analysis), and it may be that the Switch task is in fact more sensitive. In the Switch task at least two novel words are paired with two referents (word A with object A, word B with object B). At Test, some trials show the label and referent that were previously paired (A with A; Same trials) and some trials show a label with the other referent (A with B; Switch trials). In this paradigm, infants only need to associate one word–referent pair to recognize a word–object violation. If infants learn that word A should be associated with object A, they should be able to detect the violation when word A is paired with object B. However, in our preferential looking paradigm, infants needed to correctly identify both word–object pairings to show learning. Moreover, it may be that detecting a pairing violation (dishabituating in the Switch task) can be accomplished with weaker knowledge than looking towards a correct referent in a preferential looking paradigm. Tsui et al.'s (2019) meta-analysis reported an average effect of Cohen's $d = 0.33$, 95% CI [0.03, 0.63] in comparable studies using the Switch task (i.e., 14-month-olds learning dissimilar-sounding words), which was moderate and much larger than the approximate $d = 0.09$ we observed in our own data (Brysbaert & Stevens, 2018). Nonetheless, little work has compared infants' performance in the Switch task to a preferential looking test using the same learning task (although see Yoshida et al., 2009), and thus it remains an open methodological question which tasks are most sensitive for testing infant word learning. Developing maximally sensitive and reliable tasks should be a priority for research on infant word learning.

Another well-documented possibility is that sampling and measurement error in the context of small samples can lead to highly variable, and unreliable, effect-size estimates (Brysbaert, 2020; Lindsay, 2020; Oakes, 2017). For instance, underpowered studies can lead to exaggerated effect size estimates that, combined with publication bias favoring positive results, might end up published, whereas null results with similar sample sizes end up in the file drawer (Rosenthal, 1979). As mentioned in the Introduction, our sample size was chosen back in 2012, following sample sizes from other studies in the field (e.g., Fennell & Werker, 2003; Mattock et al., 2010), and after 7 years of testing infants we were not able to achieve our (small) target sample in all groups. In retrospect, we acknowledge that our original experimental plan was most likely underpowered. Even when these small groups were combined in our updated analysis, the sample was very heterogeneous, limiting our explanatory scope. At the same time, given our large overall sample, we would

have expected to find statistically reliable word learning, even if there were some moderators of an overall positive effect size. However, we explored three different variables – percent exposure to the sentence frame language, receptive vocabulary in the sentence frame language, and attention during Training – and found no effects. Despite this limitation, we believe that there is value in sharing our study, as it shows some of the drawbacks to using traditional methodologies and conventional sample sizes. Open science practices centered around transparency and collaboration, combined with more advanced statistical analyses, have an enormous potential to inform future studies on infant word learning. By planning adequate sample sizes (using power analyses and simulations), pre-registering analytical pipelines, and sharing materials, data, and research reports, we can work toward more reliable findings in the field.

Another important issue our study faced is the reduction of our initial sample size. Though we tested 288 14-month-old infants, after implementing our exclusion criteria we lost 62% of our participants for the traditional analysis and 46% for the updated one. These substantial attrition rates are common in the field and reflect the challenge of conducting research with infants. One way to achieve larger sample sizes and more robust results is with collaborations between different research labs. When participants are recruited in multiple locations, it is easier to obtain larger samples, and the results are also more generalizable and diverse. Although some researchers may find it more challenging than others to conduct large studies on their own or to engage in large-scale collaborations, it is important to consider the value of carrying out research that may not be sufficiently powered in the first place (Brysbaert, 2020; Oakes, 2017). In recent years, more opportunities to take part in such large-scale collaborations have become available, and often do not require extensive resources to join (e.g., Byers-Heinlein et al., 2020; Frank et al., 2017; ManyBabies Consortium, 2020). Similarly, open science practices such as open sharing of stimuli and protocols between researchers can be useful in identifying procedures and materials (e.g., novel objects, number of trials, etc.) that are better tolerated by infants at specific ages, reducing fussiness and participant loss.

Regardless of the limitations of our experimental design, our results are nonetheless surprising. There is a vast body of published research showing successful word learning in the lab with infants, even with methods and small sample sizes comparable to ours. Taking into account the publication bias for positive results (Carter et al., 2019; Rosenthal, 1979), it is impossible to know how many “unsuccessful” infant word learning studies languish in the file drawer. If they do exist in significant numbers, their absence from the literature may distort the picture of how easily infants learn new words in the lab, and, by consequence, any generalization to the real world outside the lab. Increasingly, journals, editors, and reviewers are recognizing the importance of publishing null results, and researchers are embracing open science practices such as pre-registration and registered reports (Tsuji et al., 2020). With these efforts, the published literature might present a more accurate picture of the true effects in hard-to-test populations, like young infants. Additionally, developing large-scale collaborations across labs, with greater power and sample diversity, might also contribute to a better characterization of infants' word learning abilities.

Overall, our study shows that word learning in the lab can be challenging for 14-month-old bilinguals and monolinguals, despite the presence of supportive linguistic cues such as sentence frames. The case study presented here highlights the need for and value of open science practices to advance our understanding of infant development.

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Data, code and materials availability statement

All data, code and stimuli used in the present study are available at the Open Science Framework. Stimuli are available at <https://osf.io/g6nrv>. Data and scripts are available at <https://osf.io/upy7f>.

Ethics statement

The current study was conducted according to the Declaration of Helsinki and ethics approval was obtained from the Human Research Ethics Board of Concordia University (certification numbers UH2011-041 and 10000439). All participants' parents gave informed written consent before taking part in the study.

Authorship and Contributorship Statement

AMGB: Writing - Original Draft, Writing - Review & Editing, Formal Analysis. RDB: Writing - Review & Editing, Formal Analysis. HK: Writing - Review & Editing, Formal Analysis. KBH: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration, Funding acquisition.

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