Investigating the Vocabulary Spurt in Bilingual and Monolingual Infants

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A Thesis

In the Department

of

Psychology

Presented in Partial Fulfillment of the Requirements

for the Degree of Master of Arts (Psychology) at

Concordia University

Montreal, Quebec, Canada

May 2024

CONCORDIA UNIVERSITY
School of Graduate Studies

This is to certify that the thesis prepared

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Entitled: Investigating the Vocabulary Spurt in Bilingual and Monolingual Infants

and submitted in partial fulfillment of the requirements for the degree of

Master of Arts (Psychology)

complies with the regulations of the University and meets the accepted standards withrespect to originality and quality.

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Abstract

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Sometime before their second birthday, many children have a period of rapid expressive vocabulary growth called the vocabulary spurt. Theories of the underlying mechanisms differ: accumulator models emphasize the accumulation of experience with words over time to yield a spurt-like pattern, while cognitive models attribute the spurt to cognitive changes. To test these theories, English–French monolingual and bilingual children with different exposure to each language were studied. Dense, longitudinal data was analyzed from 45 infants aged 16-30 months, whose expressive vocabulary was measured on a total of 617 occasions in English and/or French. Single-language (English and/or French), concept (number of concepts lexicalized across both languages), and word (sum of both languages) vocabulary scores were computed. Infants' exposure to each language and their exposure balance were measured using a language exposure questionnaire. Logistic curves were fitted to each infant's data to estimate the timing (midpoint) and steepness (slope) of the vocabulary spurt in single-language, concept, and word vocabularies. 76% of infants showed a spurt in at least one vocabulary type, and bilinguals were less likely to show one in their non-dominant than their dominant language. For single-language vocabulary, infants with more exposure to a language had earlier spurts. For combined vocabularies (concept and word), monolinguals and unbalanced bilinguals had earlier and steeper spurts than balanced bilinguals. Results better support the predictions of accumulator models than cognitive theories, and show that infants follow different vocabulary acquisition trajectories based on their language background.

Acknowledgements

I would like to thank my supervisor, Dr. Krista Byers-Heinlein, for her constant guidance and encouragement, completing this thesis would not have been possible without her. I also want to thank my thesis committee for their useful insights. Thank you to everyone at the Concordia Infant Research Lab for their help and support, particularly to Dr. Laia Fibla for co-supervising this thesis. Thank you to my family for always being present, even from a distance, and to my husband for his unwavering support and encouragement.

The research described in this thesis was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC RGPIN-2018-04390), the National Institutes of Health (NIH 1R01HD095912-01A1), and the Centre for Research on Brain, Language and Music (CRBLM); the CRBLM is funded by the Government of Quebec via the Fonds de Recherche Nature et Technologies and Société et Culture.

Contribution of Authors

The research presented in this thesis was conceptualized and the methodology was designed by Miranda Gómez Díaz and Dr. Krista Byers-Heinlein. Miranda Gómez Díaz conducted all statistical analyses, created data visualizations, and wrote the original manuscript; Dr. Krista Byers-Heinlein and Dr. Laia Fibla reviewed and edited the manuscript. Dr. Rachel Ka-Ying Tsui designed the data collection procedures.

At the time of defense the manuscript, titled "Testing Theories of the Vocabulary Spurt with Monolingual and Bilingual Infants", was in press at the journal *Developmental Psychology.*

All authors reviewed the final manuscript and approved of the contents.

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Introduction

Sometime shortly before their second birthday, children undergo what appears to be a vocabulary spurt, which is a period of rapid word learning (D'Odorico et al., 2001). While there are numerous studies investigating vocabulary spurt in monolingual infants (e.g., Kauschke & Hofmeister, 2002; D'Odorico et al., 2001; Ganger & Brent, 2004; Rescorla et al., 2000), fewer have focused on bilinguals (Silvén et al., 2014). Yet, a growing number of children around the world are raised bilingual. For example, in Quebec, Canada, where the current study took place, the proportion of French-English bilinguals aged 5 to 17 increased from 28% to 33% from 2006 to 2016 (Turcotte, 2019). Uniquely, bilingual children learn words in two different languages, which has been shown to affect their patterns of vocabulary development (Hoff et al., 2014; Silvén et al., 2014). It is still unclear whether bilingual children show the vocabulary spurt on the same schedule as monolinguals, and if so whether this is only apparent when combining vocabulary across their two languages, or whether separate spurts are observable in each language.

A better understanding of the underlying mechanisms of the vocabulary spurt may provide families who are raising bilingual infants a clearer idea on what to expect of their language development. It may also help professionals involved in early language development, such as pediatricians, educators, and speech pathologists, to differentiate typical vocabulary acquisition from potential language delays and to develop intervention programs. Thus, the current study used dense, longitudinal data from monolingual and bilingual infants with different levels of exposure to their two languages, to shed light on the fundamental mechanisms underlying the vocabulary spurt, and to identify what patterns should be expected in bilingual children.

Early Vocabulary Development

Learning words is an important part of early language development, because it supports cognitive, social, and expressive language skills later in childhood (Marchman & Fernald, 2008; Longoria et al., 2009). Vocabulary acquisition in the first years of life is marked by important milestones such as the onset of word comprehension around 6 to 9 months of age (Benedict, 1979; Bergelson & Swingley, 2011; Bleses et al., 2008) and word production around 12 months (Fenson et al., 1994).

While the majority of typically-developing infants reach these milestones around these ages, a number of factors lead to large individual differences in vocabulary acquisition trajectories. At 16 months, some infants produce as many as 180 words while others produce as few as 10 words, and still others produce no words at all (Fenson et al., 1994). Factors that have been found to impact expressive vocabulary size include infants' cognitive skills, a family history of language/learning disorders, and quantity of parental speech input (Suttora et al., 2020). One approach to understand how language input affects vocabulary development is to study bilinguals, as they have a range of input in each of their languages (e.g., one bilingual might hear English 30% of the time and another 70% of the time), and on average, they receive less input in each language than monolinguals. Comparisons between monolinguals and bilinguals typically follow one of two approaches: a single-language approach or a combined-language approach. Under the single-language approach, monolinguals' vocabulary size in their only language is compared to bilinguals' same single-language vocabulary size (e.g., measuring monolinguals' and bilinguals' English vocabularies; Hoff et al., 2012; Silvén et al., 2014). Under a combined-language approach, vocabulary size across bilinguals' both languages is compared to monolinguals' only language. Combined approaches can compute vocabulary size in two different ways: as the number of concepts lexicalized across both languages or as the sum of the vocabulary scores of each language. In this study we refer to these as concept vocabulary and word vocabulary, respectively (see Byers-Heinlein et al., 2023).

With bilinguals' exposure being divided into two languages, they tend to score lower on single-language expressive vocabulary measures for the majority language (i.e., the language spoken by the community outside the home) or their non-dominant (i.e., less-heard) language than their monolingual peers in that same language between 14 and 48 months (Byers-Heinlein et al., 2023; Hoff et al., 2014; Silvén et al., 2014). This effect has also been observed cross-linguistically in bilingual infants with minimal exposure (20% or less) to their second language (DeAnda et al., 2016).

By contrast, studies following a combined-language approach have generally observed comparable vocabulary development between bilinguals and monolinguals (Hoff et al., 2012; Pearson et al., 1993; Silvén et al., 2014). Comparing monolinguals' vocabulary to bilinguals' concept vocabulary (Pearson et al., 1993) and word vocabulary (Hoff et al., 2012; Pearson et al., 1993; Silvén et al., 2014) often yields similar, although not identical results (Byers-Heinlein et al., 2023). Yet, high variability in expressive vocabulary has been observed within these groups. Silvén et al. (2014) found that, among monolinguals and bilinguals, variability was the highest around their second birthday, with vocabularies ranging from fewer than 50 words up to 600 or more words.

One variable that has been linked to such variability amongst bilinguals is exposure balance, that is, the relative exposure to each language that children receive: Some children hear their languages in a balanced proportion (e.g., around 50% exposure to each language), whereas others hear their languages in an unbalanced proportion (e.g., 20% exposure to one language and 80% exposure to the other). This can influence the distribution of the child's overall vocabulary across the languages. For example, an infant with balanced exposure might express several concepts in both languages (i.e., many translation equivalents), while an infant with unbalanced exposure might express several concepts in the dominant language (i.e., the language with higher relative exposure) with only a few translation equivalents (Tsui et al., 2022). Hoff et al. (2014) found that when children between 22 and 48 months had relatively balanced exposure, words in the majority language comprised more than half of their expressive vocabulary. What has been understudied in bilinguals is how differences in exposure balance might affect phenomena such as the vocabulary spurt.

The Vocabulary Spurt

The vocabulary spurt is a period of rapid expressive vocabulary growth that is thought to typically occur sometime before an infant's second birthday (between 14 and 24 months of age in Silvén et al., 2014; 15 to 21 months in Kauschke & Hofmeister, 2002; around 20 months in D'Odorico et al., 2001). This phenomenon is defined as the transition between an initial stage of slow expressive vocabulary growth to a stage of more rapid growth (Ganger & Brent, 2004). Estimates for the magnitude of the vocabulary spurt (i.e., the number of words learned per unit of time) vary across studies. For example, one study reported a range of 58 to 80 words in two months (Rescorla et al., 2000), while another study reported a range of 22 to 114 words in one month (D'Odorico et al., 2001). While many children's vocabulary growth appears to follow a spurt-like growth pattern, this may not be universal. Frank et al. (2021) studied the vocabulary spurt in a large cohort for Norwegian- and English-learning children as young as 8 months and up to 35 months of age. They did not find evidence for a vocabulary spurt pattern, although data were analyzed from children with as few as four data points, which could have masked spurt-like patterns that might be observed in denser datasets.

Studies estimating the proportion of children who do show a spurt report proportions ranging from 20% (Ganger & Brent, 2004) to 72% (Goldfield & Reznick, 1990 in Ganger & Brent, 2004), depending on the criteria used to define a spurt. Others have argued that all typically-developing children show a vocabulary spurt, albeit some might show it after their second birthday, later than what would classically be expected (D'Odorico et al., 2001; Rescorla et al., 2000). A possible explanation for this is that late spurters are also late talkers. Some late talkers do show a vocabulary spurt, which has been reported to occur between 26 and 32 months of age (Rescorla et al., 2000).

Identification of the Vocabulary Spurt

The different methods used to identify a vocabulary spurt limit our understanding of this phenomenon. One of the most common methods has been the threshold approach, in which children must cross a threshold of words learned in a certain period of time in order to be considered to undergo a vocabulary spurt (D'Odorico et al., 2001; Gopnik & Meltzoff, 1987). However, there is no agreed-upon threshold for what defines a spurt, making it difficult to compare across studies. For example, Gopnik and Meltzoff (1987) identified a vocabulary spurt if children learned 10 new words in a three-week period, while D'Odorico et al. (2001) identified a vocabulary spurt if children used 20 new words in a month. The threshold approach can be unreliable, as results may differ based on the number of words or the time period used to define the threshold (i.e., a child may be considered a "spurter" or a "non-spurter" under slightly different thresholds).

To address this issue, Ganger and Brent (2004) proposed the use of a logistic curve in the study of the vocabulary spurt, as it can quantitatively model the transition between a period of slow vocabulary development and one of rapid vocabulary growth. In the logistic curve method, a vocabulary spurt is defined as an inflection point in vocabulary growth, indicating when the steepest vocabulary increase occurs. Concretely, the timing of the vocabulary spurt is identified as the midpoint of a logistic curve fit to the data, and the steepness of the spurt as the slope of the curve, that is, the rate of change of the curve (Ganger & Brent, 2004). Note that defining the vocabulary spurt in this way might yield somewhat different results from threshold approaches that often seek to identify the "onset" of the spurt, corresponding more closely to the first shoulder of the logistic curve rather than its midpoint, which occurs later. Therefore, by using a logistic curve the vocabulary spurt may be identified at a later age than what has been reported in the literature when threshold approaches have been used (D'Odorico et al., 2001; Kauschke & Hofmeister, 2002; Silvén et al., 2014). Regardless of the methods used to identify a vocabulary spurt, the mechanisms behind it are still not clearly understood.

Underlying Mechanisms of the Vocabulary Spurt

While the study of the vocabulary spurt started decades ago and has included monolingual and to some degree bilingual populations (D'Odorico et al., 2001; Kauschke & Hofmeister, 2002; Rescorla et al., 2000; Silvén et al., 2014), the mechanisms underlying this pattern of vocabulary growth remain poorly understood. Some theories posit that changes in the speed of vocabulary growth arise from changes in cognitive development, for example the “naming insight”, which is described as the moment when a child realizes that all things have names and all names refer to things (Reznick & Goldfield, 1992). Another cognitive-based theory posits that the vocabulary spurt coincides with the improvement of categorization skills (Gopnik & Meltzoff, 1987).

In contrast, more recent theories explain patterns of vocabulary growth under an accumulator model, which posits that word learning results from the accumulation of language input through repeated exposure (Hidaka, 2013; McMurray, 2007). Such models assume that experience for each word accumulates in separate and unique registers, and some words require accumulation of more exposure to be learned than others (Kachergis et al., 2022). For example, the word “ball” is easier to learn and requires less exposure than the word “today”. Once the necessary experience is accumulated for a word, that register’s threshold is reached, and the word is produced. In this view, a pattern of accelerated learning results from the accumulation of enough language experience. If many early words attain sufficient exposure for acquisition around the same age, a spurt-like pattern will emerge with no contribution from specialized cognitive processes (McMurray, 2007).

Testing different models of vocabulary growth is challenging, because children tend to undergo cognitive development and gain language experience concurrently. However, data from bilingual children provides a unique opportunity for testing the previously mentioned theories of the vocabulary spurt, as experience with a specific language is dissociated from cognitive development because they often hear their languages in different proportions. To our knowledge, the only study to date that has yielded data relevant to the vocabulary spurt in bilingual infants was conducted by Silvén et al. (2014). The study compared expressive vocabulary growth trajectories between two groups, Finnish monolingual (N = 26) and Finnish-Russian bilingual infants (N = 28). Expressive vocabulary was measured four times from 14 to 36 months of age following both a single-language and combined-language approach: bilinguals’ vocabulary was measured in Finnish (the majority language) and Russian (the minority language) separately, and then these scores were summed as word vocabulary, while monolinguals’ vocabulary was measured in Finnish. Although the study did not specifically refer to the construct of a vocabulary spurt, results showed that most children’s vocabularies had a non-linear growth trajectory, with the greatest growth occurring during the second or third year. When comparing the two groups’ trajectories, monolinguals’ single-language vocabulary increased faster than bilinguals' vocabulary in Finnish and Russian separately, but not when both languages were combined. Bilinguals' vocabulary development differed in each language, with Russian (their non-dominant language) developing more slowly than Finnish (Silvén et al., 2014). Overall, these results suggest that, at least under accumulator theories, bilingual infants might experience a vocabulary spurt in one or both of their languages later in time than monolinguals, due to their reduced exposure to each language. Nonetheless, the conclusions that can be drawn from the study are limited, as vocabulary was only measured every six months and language exposure was analyzed categorically (monolingual vs. bilingual). Collecting denser vocabulary data and analyzing language exposure as a continuum would allow a better understanding of the relation between language exposure and the vocabulary spurt, and thus provide a clearer test of current theories.

The Present Study

The primary goal of this research was to test competing theories about the role of cognitive maturation versus language experience on the vocabulary spurt by looking at children varying in exposure to English and French. The secondary goal was to describe the vocabulary spurt in bilingual children, in terms of the percentage of children who show a spurt, and how bilingualism might change the expected timing and trajectory of the spurt in each language and when both languages are combined. We additionally aimed to understand the nature of development in children who do not show a vocabulary spurt.

Our approach was to examine how language exposure is related to the vocabulary spurt in longitudinal data collected monthly from infants learning English and/or French, who had a range of language exposure from monolingual (>90% exposure to one language) to balanced bilingual (~50% exposure to each language). We determined whether and when a vocabulary spurt had occurred and its steepness in each of the child's languages, as well as (where applicable) when both languages were combined. Finally, we compared vocabulary size at both the beginning (18 months) and end (30 months) of data collection in spurters and non-spurters.

If cognitive development is a key driver of the trajectory of vocabulary development, the vocabulary spurt should be apparent in both languages on the same schedule and with a similar slope, and in turn when both languages are combined. By contrast, if the accumulation of exposure is a key driver of the vocabulary spurt, then the vocabulary spurt should occur earlier and the curve should be steeper when a child has higher exposure to a particular language. This latter possibility aligns with our predictions, given existing evidence in favor of accumulator models of vocabulary development (Hidaka, 2013; McMurray, 2007). In line with previous research on the nature of bilinguals' combined vocabularies (Hoff et al., 2012; Pearson et al., 1993), we did not expect the exposure balance to have an influence on the occurrence of the spurt and slope of the curve of the combined vocabularies, although we tested this as a possibility. In regards to the vocabulary size of non-spurters, while we did not make a-priori predictions, it is reasonable to expect that they might have smaller vocabulary sizes than spurters, particularly after the age when the vocabulary spurt tends to occur (i.e., at the end of data collection).

Method

This study was approved by the Concordia University Human Research Ethics Committee [certification #10000439]. We report all data exclusions and all measures used in the study. Data cleaning and analysis were carried out in RStudio version 2023.3.0.386 (Posit team, 2023) using R version 4.2.2 (R Core Team, 2022). A full list of the packages used and their versions can be found in Table A1 in the appendices. This study's hypotheses and analysis plan were preregistered. We report the main sample and analyses in the main text. As described below, several robustness analyses (fully reported in Appendix B) were performed to ensure that results were not dependent on specific analytical decisions. The overall patterns of results did not change.

For preregistration see https://osf.io/4sdzf/?view_only=e2b7e7dfd04c4ef892575b7ade045b72
For code see https://osf.io/v9q76/?view_only=a98f48d480c5408bbc9fabd498cbf681

Participants

The final analyzed sample consisted of 45 infants without any apparent health/developmental issues, who contributed longitudinal data on a total of 617 measurement occasions. The sample included bilingual infants (i.e., exposed to at least 10% of both English and French) and monolingual infants (i.e., exposed to more than 90% of English or French), although language exposure was analysed as a continuous variable in most of our analyses, rather than as a categorical variable. These data were part of a larger study where parents were asked to contribute data longitudinally on a monthly basis from 16 to 30 months of age (note that there were some missing data, discussed further below). This age range corresponds to that for the MacArthur-Bates Communicative Development Inventories (CDI): Words and Sentences Forms (Boudreault et al., 2007; Marchman et al., 2023). Most parents had at least some post-secondary education, and family incomes were generally high: 50% of families had a disclosed yearly income greater than 100,000 CAD, and 95% of families had disclosed yearly incomes of greater than 50,000 CAD, which is above the Statistics Canada (2023) low-income cutoff for a family of 4 in large urban centers. Participants' demographic characteristics are presented in Table 1.

Language Exposure Inclusion Criteria

Participants heard English and/or French 10-100% of the time and were not regularly exposed to additional languages (less than 10% exposure). All infants were living in Montreal at the time of data collection, a city where both English and French are widely spoken, in addition to a variety of other languages. In this context, English and French both have high status in the community and both English-dominant and French-dominant people share similar attitudes towards these languages (Kircher, 2014). It was possible that infants' language exposure changed over time, for example due to changes in childcare or daycare entry. Thus, we restricted our analyzed sample to infants whose exposure to French and English remained within a 20% range throughout the study (i.e., the difference between minimum and maximum exposure at any two time points during the study did not exceed 20%), with exposure to additional languages remaining below 10%. We reasoned that a change greater than this, or regular exposure to more than two languages, might affect vocabulary growth in unexpected ways.

Table 1 Demographic characteristics of participants (N = 45)

	N	%
Child sex		
Girls	16	36
Boys	27	60
Another gender	2	4
Birth order		
First-born	27	60
Later-born	16	36
Did not report	2	4
Annual family income (CAD)		
25000-50000	2	4
50000-75000	4	9
75000-100000	10	22
>100000	26	58
Prefer not to disclose	3	7
Ethnicity		
White	36	80
Mixed ethnicity	6	13
Another ethnicity	2	4
Did not report	1	2
Language group		
Bilingual	29	64
Monolingual	16	36
Language dominance		
English-dominant	19	42
French-dominant	26	58
Caregiver who completed CDIs (617 occasions)		
Mother	547	89
Father	10	2
Both caregivers	14	2
Different parent in each language	46	7
	M(*SD*)	Range
Parental education		
Maternal education in years	17.56 (2.08)	12-23
Paternal education in years	17.17 (2.59)	12-23
Starting age in months	16.76 (0.45)	16.10-17.96
Language balance	24.93 (18.10)	0-49.9

Missing Longitudinal Data

Given the longitudinal nature of the study, it was not uncommon for participants to have some missing data for particular months in one or more vocabulary types, that is, single-language (English and/or French), concept, and word. Missing data ranged from 0 to 6 data points per participant for each vocabulary type (*M* = 1.47, *SD* = 1.58 across all vocabulary

types). The maximum number of possible observations per infant was 15, which could be reached if they joined the study at 16 months and submitted data every month until 30 months of age. Infants were included in the sample only if they had gaps of two months or fewer in their CDI data in at least one of their languages, as we reasoned that this would still allow us to identify a vocabulary spurt with tight precision in that language. We omitted data from languages with larger gaps such that not all infants contributed data to all measures. Infants in the final sample contributed data on between 10 and 15 occasions (*M* = 13.71, *SD* = 1.36).

Missing data were handled such that we included the data of these participants only in the language where they did not have a change in language exposure or missing data, but excluded data in their other language as well as the concept and word scores, as the combined-language scores were estimated with data from only one of their languages. A robustness analysis was performed by also excluding timepoints where data were missing in either language.

Final Sample

Data collection for the larger project began when infants were between the ages of 16 months 0 days and 20 months 31 days; data was collected between August 2020 and April 2023, with participants joining the study at different times. Monolingual literature suggests that the vocabulary spurt typically occurs around 18 months (Kauschke & Hofmeister, 2002). It is possible that infants who began the study after this age experienced a vocabulary spurt before joining, and therefore their vocabulary spurt would not be captured in our data. To account for that possibility, we included only the infants that started the study between 16 months 0 days and 18 months 0 days of age. A robustness analysis was performed without excluding infants based on age at Time 1, in case they showed a vocabulary spurt later than expected.

The analyzed sample of 45 infants was a subset of this larger dataset that included a total of 117 infants learning English and/or French, who were selected based on the pre-registered inclusion criteria described above. In total, we excluded 9 infants with reported health or developmental issues, 3 who had exposure to a third or fourth language of 10% or greater, 28 who had three or more consecutive months of missing data in both of their languages, and 32 who were older than 18 months 0 days when they joined the larger study.

Measures

Language Exposure

An adaptation of the Language Exposure Questionnaire (LEQ; Bosch & Sebastián-Gallés, 2001) using the Multilingual Approach to Parent Language Estimates (MAPLE; Byers-Heinlein et al., 2020) was used to measure language exposure. This structured interview assesses the infant's language environment and yields a percentage estimate of their relative exposure to each of their languages from birth up until day of assessment. It has been shown to have strong reliability in a French-English bilingual population in relation with full-day recordings ($r = .76$, $p < .001$; Orena et al., 2020). Language exposure was largely analyzed as a continuous variable; this allowed us to study infants who are typically considered monolingual (>90% exposure to one language) and infants who are typically considered bilingual. Also, this approach made it possible to evaluate how variance in exposure may have an effect on vocabulary growth, and produced more detailed results than those obtained by transforming this continuous data into categories (Kremin & Byers-Heinlein, 2021). Language balance was measured as infants' exposure to their non-dominant language (i.e., the lesser heard language).

Vocabulary Size

Expressive vocabulary was measured using an online version of the MacArthur-Bates Communicative Development Inventories (CDI): Words and Sentences form in its American English and Canadian French adaptations (Boudreault et al., 2007; deMayo et al., 2021; Marchman et al., 2023). The CDI is a widely used parent vocabulary checklist of expressive vocabulary that has proven to be a reliable instrument in its American English version ($r = .95$, $p < .01$; Fenson et al., 1994) and its Canadian French version (Boudreault et al., 2007) at ages 19–21 months ($r = .82$, $p < .001$) and 26–28 months ($r = .84$, $p < .001$; Trudeau & Sutton, 2011), as well as in the study of bilingual infants (Hoff et al., 2014). We computed single-language vocabulary scores for each of the child's languages (French and/or English). Vocabulary scores that combined both languages were estimated in two different ways as proposed by Pearson et al. (1993): a concept vocabulary score and a word vocabulary score. Concept vocabulary, representing the number of concepts lexicalized, was computed as the total words produced across both languages minus the number of translation equivalents the child produced (i.e., concepts that the child produced in both English and French), which were thus counted only once. Word vocabulary was calculated as the sum of both single-language vocabularies. For example, if a child produced the words cat, dog, ball, apple, and cookie in English and the words *chat* ("cat"), *couche* ("diaper"), *banane* ("banana"), and *fleur* ("flower") in French, the single-language vocabulary would be 5 in English and 4 in French, the concept vocabulary would be (9 - 1) = 8, because the concept cat/*chat* was counted only once, and the word vocabulary would be 9. For monolingual infants all three vocabulary types (single-language, concept, and word) yielded the same score.

Procedure

At the onset of the study, which was when the infant was 16-18 months-old, the primary caregivers completed the LEQ via video call. The LEQ was updated every five months in the same manner until the end of the study, when the LEQ was completed a final time at 30 months. Parents were asked to contribute CDI data every month if possible, with the last wave of data collection occuring when the infant was 30 months old. Parents received links to the CDI in English and in French, except in cases where infants had less than 10% exposure to a particular language (i.e., monolinguals) wherein caregivers were asked to complete the form in only a single language. Blank CDIs were sent to parents on their initial month of participation; in subsequent months they received and updated pre-filled out forms with the information from the previous wave, although parents could and did uncheck words that their child no longer said. Parents could decide who would fill out the CDIs: one parent could fill out both forms, a different parent could fill out each form, or both parents could fill out a form together (see Table 1).

Data Analysis

We measured the vocabulary spurt longitudinally at the infant level, that is, each infant's vocabulary trajectory was analyzed individually, separated by vocabulary type. Data analysis was carried out in two steps. First, individual logistic curves were fitted to each infant's data on the three different vocabulary types (i.e., single-language, concept, and word) to estimate the timing and steepness of the vocabulary spurt. Second, linear and mixed effects models were used to investigate whether these parameters were related to language exposure and balance within each vocabulary type.

Step 1: Timing and Steepness of the Vocabulary Spurt

To estimate the timing and steepness of the vocabulary spurt, we used the drm function from the drc package in R (Ritz et al., 2015). Specifically, a logistic curve was fitted to each infant's data in single-language (English and French separately), concept, and word vocabularies as dependent variables, with age as the independent variable. We specified a four-parameter log-logistic function, fitting the following coefficients: lower limit (fixed to 0, as infants cannot know a negative number of words), upper limit (the maximum estimated vocabulary size an infant had at the end of the study), midpoint (i.e., the steepest point of the curve), and slope (i.e., scale parameter). The midpoint corresponds to the age when the steepest vocabulary increase occurred (i.e., vocabulary spurt). The slope can be described as a growth factor that reflects the overall steepness of the curve (Mahr, 2019) – the larger the absolute value, the steeper the curve.

Step 2: Relation Between the Vocabulary Spurt and Language Exposure

After obtaining the midpoint and slope for each infant in each single-language (English and French separately) and for their concept and word vocabularies, we ran six models to assess the relation between the vocabulary spurt and language experience. Preliminary analyses were conducted controlling for family annual income, maternal education, child gender, and birth order. Results did not show effects of these variables on the outcomes and therefore they were not included in subsequent models. For the main analyses, mixed-effects models were performed for single-language vocabulary (see Models 1 and 2), where English and French scores were entered with the relative exposure to each language as the predictor and a by-subject random intercept to account for bilingual infants' repeated measures in each language. Scores from both languages were entered in the same model as we did not expect any systematic differences between the languages; separate models, one per language, were performed as part of robustness analyses to corroborate this.

$$\text{single\_language\_midpoint} \sim \text{exposure\_percent} + (1|\text{participant}) \tag{1}$$

$$\text{single\_language\_slope} \sim \text{exposure\_percent} + (1|\text{participant}) \tag{2}$$

We ran linear models for concept vocabulary (see Models 3 and 4) and word vocabulary (see Models 5 and 6) with exposure balance as the predictor. As a robustness analysis, we also ran a version where monolingual infants were excluded from these models.

$$\text{concept\_midpoint} \sim \text{exposure\_balance} \tag{3}$$

$$\text{concept\_slope} \sim \text{exposure\_balance} \tag{4}$$

$$\text{word\_midpoint} \sim \text{exposure\_balance} \tag{5}$$

$$\text{word\_slope} \sim \text{exposure\_balance} \tag{6}$$

Exploratory Analyses

We conducted several exploratory analyses that were not preregistered. In addition to the slope, we measured the vocabulary spurt's magnitude as the number of words learned during the spurt, as this information may be more observable and valuable to parents and clinicians. Linear and mixed-effects models were performed with the number of words learned during the vocabulary spurt as the dependent variable. The mixed-effects model for single-language vocabulary included language exposure percent as the predictor and a by-subject random intercept (see Model 7). Linear models for concept (see Model 8) and word (see Model 9) vocabularies included exposure balance as the predictor. Following the approach of Frank et al. (2021), to estimate the number of words learned during the month surrounding the vocabulary spurt (i.e., half a month before and after) as identified by the Step 1 model, we calculated the number of words learned between the CDI measurement immediately prior to and the one immediately after the identified age of the spurt (e.g., if the spurt was estimated at 19.5 months, the difference in words reported at the 19-month and 20-month measurement), and pro-rated this by 30 days (i.e., one month), given that the time between sequential measurements varied (i.e., parents did not necessarily complete the CDIs exactly one month apart, and in some cases skipped a month).

$$\text{single\_language\_words\_learned} \sim \text{exposure\_percent} + (1|\text{participant}) \quad (7)$$

$$\text{concept\_words\_learned} \sim \text{exposure\_balance} \quad (8)$$

$$\text{word\_words\_learned} \sim \text{exposure\_balance} \quad (9)$$

After calculating the timing of the vocabulary spurt in Step 1, we found that some participants had an estimated vocabulary spurt outside the study's age range (i.e., before 16 months or after 30 months) in one or more vocabulary types. These participants were considered non-spurters in the corresponding vocabulary types. To assess whether there were differences in vocabulary size between spurters and non-spurters at 18 months, when the vocabulary spurt has been typically reported to occur (Kauschke & Hofmeister, 2002), and whether these differences persist after the spurt, independent samples t-tests were performed for each vocabulary type (English, French, concept, and word) to compare spurters and non-spurters at 18 and 30 months in terms of their vocabulary size.

Results

Proportion, Timing, and Magnitude of Identified Vocabulary Spurts

We attempted to fit logistic curves for each infant in each vocabulary type. Out of the 45 infants in the final sample, a vocabulary spurt could be identified on at least one vocabulary type for 35 of them (76%; see Figure 1), while for the remaining 11 infants (24%) we could not identify a vocabulary spurt for any vocabulary type. Most (88%) monolinguals showed a spurt in their only language; 66% of bilinguals showed a spurt in their dominant language (i.e., the language that they heard the most), while only 43% of them showed a spurt in their non-dominant language (i.e., the less heard language). Included in the non-spurter group was one outlier who only had an identifiable spurt for concept vocabulary but only learned 2 concepts during that month. The following results describe the remaining 34 participants.

The characteristics of the vocabulary spurt were similar for single-language, concept, and word vocabulary types. The age at which infants showed a vocabulary spurt (midpoint) was 24.28 months (*SD* = 2.69) on average across measures, and ranged widely from 18 to 29 months. On average, monolinguals showed a spurt at 23.06 months (*n* = 14, *SD* = 2.54), while bilinguals spurted later than monolinguals, and slightly earlier in their dominant (*n* = 19, *M* = 24.87, *SD* = 2.53) than in their non-dominant (*n* = 12, *M* = 25.30, *SD* = 2.76) language.

The slope of the vocabulary growth curve was 9.78 (*SD* = 3.01) on average across measures, and ranged from 5 to 22. The number of words learned during the one-month period around the vocabulary spurt was 63 (*SD* = 33) on average across measures and ranged from 8 to 174. On average, monolinguals learned 66 (*n* = 14, *SD* = 23) words during the month-long period around the vocabulary spurt, while bilinguals learned 57 (*n* = 19, *SD* = 28) words in their dominant and 43 (*n* = 12, *SD* = 40) words in their non-dominant language. See Table 2 for a breakdown of the number and percentage of infants who spurted in each vocabulary type, the mean and range of ages for the spurt, and its magnitude in each vocabulary type.

Figure 1 Individual Logistic Curves of Vocabulary Size by Age

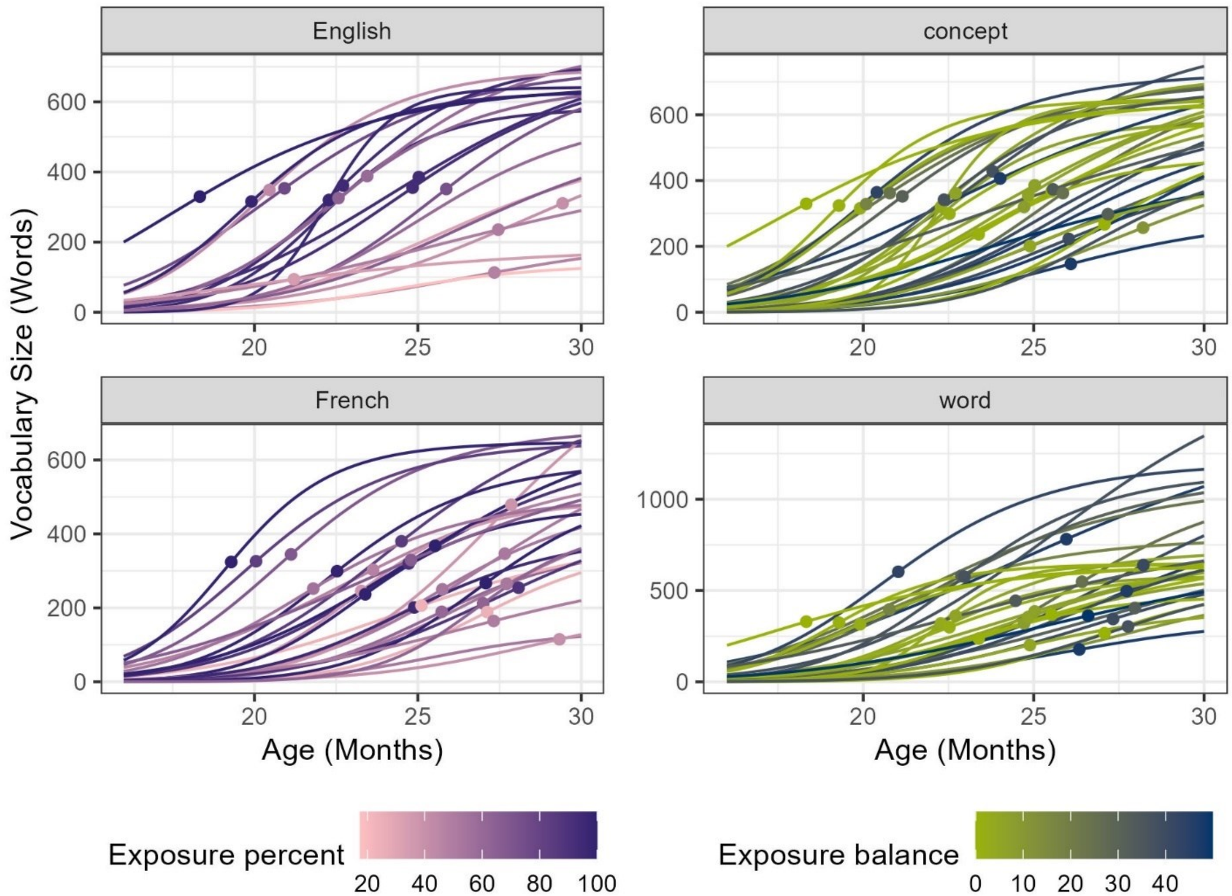

Figure 1. Individual logistic curves graphing vocabulary size in words across age in months. Each panel in the graph corresponds to a vocabulary type (English, French, concept, and word) for infants with an identifiable spurt in that vocabulary type (note that an infant can be included in only one or several of the panels). The dots on each curve correspond to the estimated midpoint (i.e., the timing of the vocabulary spurt). The color of each line and dot reflects the infant's language exposure to English and French (left panels, where light pink corresponds to low exposure and dark purple to high exposure), and their exposure balance (right panels, where light green corresponds to less balanced exposure and dark blue to more balanced exposure). Note that the scale on the y axis varies according to the largest vocabulary size reached on each vocabulary type.

Table 2 Descriptive Statistics of the Timing and Magnitude of the Vocabulary Spurt

Measure	English (*n* = 19, 51% spurters)		French (*n* = 26, 72% spurters)		concept (*n* = 32, 73% spurters)		word (*n* = 32, 73% spurters)	
	M (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range
Age of steepest vocabulary growth (Midpoint)	23.58 (2.7)	18.33 - 27.46	25.04 (2.59)	19.29 - 29.33	23.89 (2.62)	18.33 - 28.21	24.47 (2.79)	18.33 - 28.49
Steepness of curve (Slope)	9.69 (3.64)	5.32 - 21.96	10.12 (2.37)	5.67 - 16.42	9.8 (3.08)	4.72 - 21.96	9.55 (3.12)	5.3 - 21.96
Words learned during month of spurt	59.98 (35.32)	8.42 - 132.2	53.15 (27.93)	21.7 - 137.78	60.45 (26.46)	22.45 - 125.73	75.15 (37.57)	25.66 - 173.82

Note. Due to sample characteristics and exclusion criteria, each vocabulary type had different group sizes; the percentage next to group size refers to the percentage of infants that spurted in that vocabulary type.

Effects of Language Exposure on the Vocabulary Spurt

Two separate mixed effects models were conducted for single-language vocabulary. The midpoint and slope were the dependent variables in each of these models, with language exposure percent as the predictor and a by-participant random effect (see Table 3). Results for the first model showed a statistically significant and negative effect of exposure percent on the midpoint. Therefore, infants who had higher exposure to a particular language showed an earlier vocabulary spurt in that language. For the second model, results showed a non-significant effect of exposure percent to a language on the slope for that particular language, indicating that infants with higher and lower exposure had similarly steep slopes (see Figure 2).

Four linear models were conducted for the combined (i.e., concept and word) vocabularies. They had midpoint and slope as dependent variables, with the exposure balance as the predictor. For concept vocabulary (see Table 4), the effect of exposure balance was positive and marginally significant on the midpoint, and negative and marginally significant on the slope. Therefore, children with a more balanced exposure showed a slightly later and less steep concept vocabulary spurt (see Figure 2).

For word vocabulary (see Table 5), the effect of exposure balance was positive and statistically significant on the midpoint and negative and statistically significant on the slope. Overall, children who had more balanced language exposure showed a later, less steep word vocabulary spurt than those with less balanced exposure (see Figure 2).

Table 3 Results of mixed-effects models for single-language vocabulary

Predictor	*B*	*SE*	*B* 95%CI	Standardized β	β 95%CI	*p*
Midpoint						
Fixed effects						
Intercept	27.71	1.08	[25.52, 29.89]			<0.001
Exposure percent	-0.05	0.01	[-0.08, -0.02]	-0.44	[-0.70, -0.17]	0.002
Random effects						
Participant	3.32					
Slope						
Fixed effects						
Intercept	9.97	1.14	[7.66, 12.28]			<0.001
Exposure percent	0.00	0.01	[-0.03, 0.03]	0.02	[-0.23, 0.26]	0.878
Random effects						
Participant	1.62					
Words learned/month						
Fixed effects						
Intercept	29.40	13.04	[3.06, 55.73]			0.030
Exposure percent	0.40	0.18	[0.04, 0.75]	0.32	[0.03, 0.61]	0.031
Random effects						
Participant	12.41					

Note. N = 45 (34 groups). *Midpoint:* R^2 (fixed effects) = 0.18, R^2 (total) = 0.60, AIC = 221.12. *Slope:* R^2 (fixed effects) = 0.00, R^2 (total) = 0.77, AIC = 231.36. *Words learned/month:* R^2 (fixed effects) = 0.10, R^2 (total) = 0.29, AIC = 435.62. The models' intercepts corresponded to exposure percent = 0.

Figure 2 Relations Between Language Exposure and the Timing and Steepness of the Vocabulary Spurt

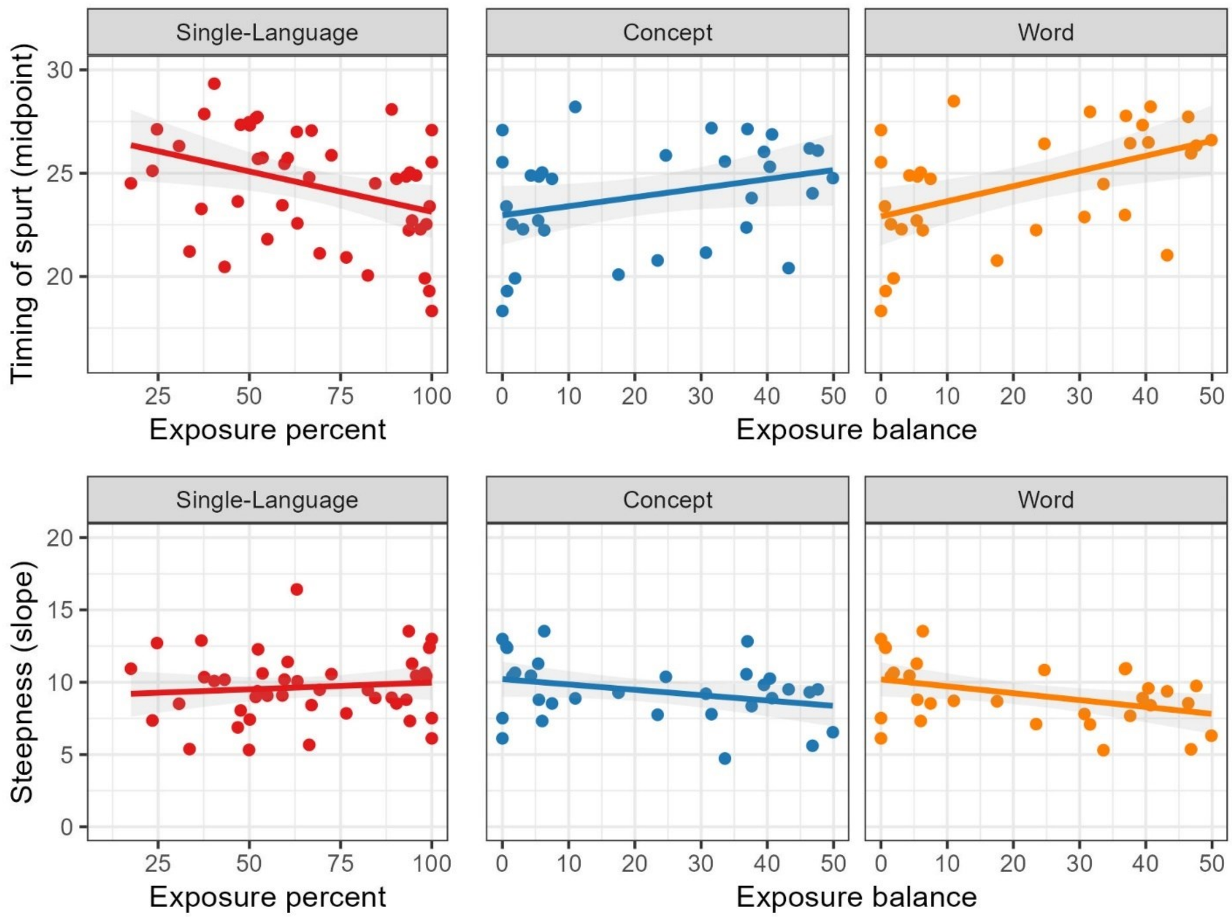

Figure 2. Note. Visualization of the relationship between timing (top row) and steepness (bottom row) of the vocabulary spurt with language exposure percent for single-language vocabulary (left column), and with language exposure balance for concept (middle column) and word (right column) vocabularies. Each dot represents a participant's data in each vocabulary type. Lines represent the model fit to the data with standard deviation in a gray shade.

Table 4 Results of linear models for concept vocabulary

Predictor	*B*	*SE*	95%CI	Standardized β	β 95%CI	*p*
Midpoint						
Intercept	22.96	0.70	[21.54, 24.38]			<0.001
Exposure balance	0.04	0.02	[-0.01, 0.09]	0.31	[-0.05, 0.66]	0.090
Slope						
Intercept	11.03	0.81	[9.38, 12.68]			<0.001
Exposure balance	-0.06	0.03	[-0.12 – 0.00]	-0.34	[-0.69, 0.01]	0.055
Words learned/month						
Intercept	67.75	7.16	[53.12, 82.38]			<0.001
Exposure balance	-0.34	0.26	[-0.87 – 0.18]	-0.24	[-0.60, 0.13]	0.193

Note. $N = 32$. *Midpoint:* $R^2 = 0.09$, adj. $R^2 = 0.06$, AIC = 154.31. *Slope:* $R^2 = 0.12$, adj. $R^2 = 0.88$, AIC = 163.79. *Words learned/month:* $R^2 = 0.06$, adj. $R^2 = 0.02$, AIC = 303.60. The models' intercepts corresponded to exposure balance = 0.

Table 5 Results of linear models for word vocabulary

Predictor	*B*	*SE*	95%CI	Standardized β	β 95%CI	*p*
Midpoint						
Intercept	22.90	0.68	[21.51, 24.29]			<0.001
Exposure balance	0.07	0.02	[0.02, 0.12]	0.48	[0.15, 0.81]	0.005
Slope						
Intercept	11.01	0.79	[9.39, 12.64]			<0.001
Exposure balance	-0.07	0.03	[-0.13, -0.01]	-0.40	[-0.74 – -0.06]	0.022
Words learned/month						
Intercept	68.34	10.34	[47.22, 89.45]			<0.001
Exposure balance	0.32	0.37	[-0.44, 1.08]	0.16	[-0.21, 0.52]	0.395

Note. $N = 32$. *Midpoint:* $R^2 = 0.23$, adj. $R^2 = 0.21$, AIC = 153.04. *Slope:* $R^2 = 0.16$, adj. $R^2 = 0.13$, AIC = 162.87. *Words learned/month:* $R^2 = 0.02$, adj. $R^2 = -0.01$, AIC = 327.09. The models' intercepts corresponded to exposure balance = 0.

Number of Words Learned During the Spurt

We conducted linear and mixed-effects models with the number of words and concepts learned during the month surrounding the vocabulary spurt as the dependent variable. As in the previous models, the single-language vocabulary model included language exposure percent as the predictor and a by-participant random effect; the concept and word vocabulary models had exposure balance as the predictor. Results from the single-language model showed a positive and statistically significant effect of exposure percent on the number of words learned during the month-long period around the vocabulary spurt (see Table 3), that is, infants who had a higher exposure to a language learned more words during the month-long period of their vocabulary spurt. The models for the combined languages did not show a statistically significant effect of exposure balance on the number of concepts (see Table 4) or words (see Table 5) learned during the vocabulary spurt (see Figure 3).

Figure 3 Relations Between Language Exposure and the Number of Words Learned During the Vocabulary Spurt

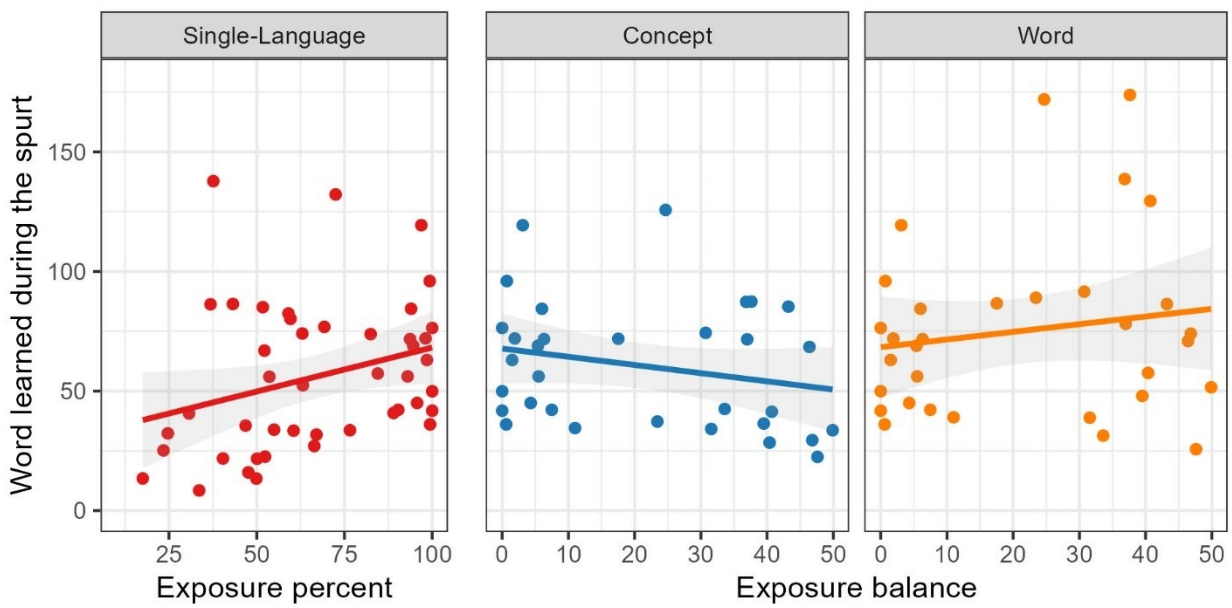

Figure 3. Visualization of the relationship between the number of words learned during the vocabulary spurt with language exposure percent for single-language vocabulary (left panel), and with language exposure balance for concept (middle panel) and word (right panel) vocabularies. Each dot represents a participant's data in each vocabulary type. Lines represent the model fit to the data.

Differences Between Spurters and Non-Spurters

We also sought to understand differences between spurters and non-spurters. Independent samples *t*-tests were conducted to compare the vocabulary sizes of spurters and non-spurters both prior to the vocabulary spurt (18 months; data were missing for 3 infants) and at the end of the study (last data collected around 30 months). At 18 months, spurters had a larger vocabulary size than non-spurters in English [$t(21.46) = 2.46$, $p = .023$], French [$t(30.84) = 2.39$, $p = .023$], concept [$t(35.61) = 3.33$, $p = .002$], and word [$t(35.58) = 3.27$, $p = .002$] vocabularies. At 30 months, spurters also had a larger vocabulary size than non-spurters in English [$t(24.90) = 3.74$, $p < .001$], French [$t(13.64) = 3.31$, $p = .005$], concept [$t(10.68) = 3.46$, $p = .006$], and word [$t(14.67) = 2.44$, $p = .028$] (see Table 6).

Discussion

Our study investigated the vocabulary spurt, its underlying mechanisms, and its universality, using dense, longitudinal data from monolingual and bilingual infants with a wide range of language exposure. This provided a unique opportunity to test competing theories about the mechanisms underlying the vocabulary spurt, because cognitive maturation and the accumulation of experience can be dissociated in our sample. We found that the accumulation of language experience plays a key role in whether, when, and how a vocabulary spurt occurs and that infants may follow different vocabulary acquisition trajectories based on their language exposure.

Underlying Mechanisms of the Vocabulary Spurt

Overall, our results better support accumulator models of the vocabulary spurt (Hidaka, 2013; Kachergis et al., 2022) than cognitive theories (Gopnik & Meltzoff, 1987; Reznick & Goldfield, 1992). Under cognitive theories, infants go through a vocabulary spurt due to cognitive changes such as a “naming insight” (Reznick & Goldfield, 1992) or improved categorization skills (Gopnik & Meltzoff, 1987). Cognitive theories predict that the spurt should occur similarly across bilinguals’ languages, or when both languages are combined. By contrast, under accumulator models, infants accumulate experience for each word in separate “registers”, and the spurt occurs when many words reach their register’s threshold around the same time (Kachergis et al., 2022; McMurray, 2007). Under this framework, infants with more exposure to a language should reach each word’s threshold more quickly than those with less exposure to a language, leading to an earlier and steeper spurt. Indeed, predictions based on accumulator models were borne out in our data: for single-language vocabulary, infants with higher exposure to a language showed an earlier vocabulary spurt in that language. Additionally, exploratory analyses provided some evidence that the magnitude of the spurt was larger, as infants learned more words in a language during the month-long period around their vocabulary spurt when they had a higher exposure to that language, although we note that this analysis did not find a significantly steeper spurt among infants with higher exposure.

Table 6 Descriptive Statistics of Vocabulary Size at 18 and 30 Months

Vocab. Type	18 Months						30 Months					
	Non-Spurters			Spurters			Non-Spurters			Spurters		
	N	*M* (*SD*)	Range	*N*	*M* (*SD*)	Range	*N*	*M* (*SD*)	Range	*N*	*M* (*SD*)	Range
English	15	25 (28)	3 - 115	19	83 (99)	5 - 360	17	267 (170)	73 - 584	20	521 (186)	130 - 680
French	10	22 (13)	11 - 50	25	57 (70)	1 - 298	10	255 (128)	76 - 455	26	456 (165)	127 - 659
concept	10	31 (15)	16 - 59	31	91 (96)	3 - 360	11	351 (151)	98 - 512	33	557 (130)	237 - 732
word	11	39 (19)	25 - 83	30	105 (105)	3 - 360	12	470 (214)	98 - 725	32	696 (262)	286 - 1334

We additionally examined the role of exposure balance on the timing and steepness of the spurt when both languages are combined (i.e., concept and word vocabularies). While we did not predict any effects of exposure balance on these vocabulary types, we did find some evidence suggesting some effects linked to the specific characteristics of language exposure (balanced vs. unbalanced) that generally better align with accumulator models rather than cognitive theories.

For word vocabulary (the sum of both single-language vocabularies), balanced bilinguals showed a later and less steep vocabulary spurt than monolinguals and unbalanced bilinguals, although infants learned similar numbers of words during the spurt regardless of exposure balance. Under accumulator models, translation equivalents (e.g., English dog and French *chien*) are presumably learned as separate unique words, each with their own register, regardless of their shared meaning. Balanced bilinguals have more distributed experience with their languages, which would result in words from both languages reaching their learning threshold later. However, bilingual infants accumulate experience for the same number of words regardless of exposure balance. These patterns might lead balanced bilinguals' vocabulary growth to be more gradual, resulting in later and less steep spurts than monolinguals and unbalanced bilinguals, but possibly with similar numbers of words learned during the spurt.

With regards to concept vocabulary (the number of concepts lexicalized across both languages), similar to word vocabulary, balanced bilinguals' spurt was marginally later and less steep than monolinguals and unbalanced bilinguals, although the number of concepts learned during the spurt was similar regardless of exposure balance. In considering the vocabulary spurt in concept vocabulary, it is important to mention that accumulator models have been conceptualized under monolingual norms of language experience (Kachergis et al., 2022), where each concept tends to have a single label. However, bilinguals learn words for the same concept in each language, that is, translation equivalents (e.g., dog and *chien*). Under accumulator models, experience for these would presumably accrue in separate registers just as any two conceptually unrelated words do. Nonetheless, there is some evidence, especially for younger infants, that translation equivalents are learned more easily than singlets (i.e., the first word learned for a referent; Bilson et al., 2015, Tsui et al., 2022), which is not easily accounted for by current accumulator models (see also Tan et al., 2024). At present, accumulator models most clearly apply to the vocabulary spurt in single-language and word vocabularies; future studies and theoretical approaches could aim to expand vocabulary spurt models to bilingual acquisition of concepts.

Universality of the Vocabulary Spurt

The literature has reported a wide range in the proportion of children identified as spurters versus non-spurters, ranging from 20% (Ganger & Brent, 2004) to 72% (Goldfield & Reznick, 1990 in Ganger & Brent, 2004). This variability may be due to the different age ranges included in studies or due to different criteria and approaches being followed to identify a vocabulary spurt. As a result, researchers have proposed a variety of arguments regarding the universality of the vocabulary spurt. Some authors suggest that relatively few infants show a vocabulary spurt (Frank et al., 2021; Ganger & Brent, 2004), while others posit that all infants show this pattern but that some infants spurt later than classically expected (D'Odorico et al., 2001; Rescorla et al., 2000). A middle ground argument proposes that the vocabulary spurt is not universal, but that most typically developing infants show it (Goldfield & Reznick, 1990 in Ganger & Brent, 2004). Our results better align with this position: we found that 76% of infants showed a spurt in at least one vocabulary type, although several of these infants (29% of bilinguals) had a spurt only in one of their two languages. This could be explained by the nature of their language exposure, for instance, more bilingual infants showed a spurt in their dominant language than in their non-dominant.

We consider two explanations for cases where infants did not appear to have a vocabulary spurt: either some infants do not show a spurt-like pattern (in one or both languages), and/or our study did not capture these infants' vocabulary spurt. Considering the first alternative, it may be that some infants simply follow more linear trajectories and therefore do not show the logistic pattern we used to identify a spurt. We found, for all vocabulary types, that non-spurters had a smaller vocabulary size at 18 and 30 months of age, which could suggest that these infants are "late talkers". This aligns with evidence of late talkers having smaller expressive vocabulary sizes than their peers between the ages of 18 and 35 months (Rescorla, 2011), and showing a less evident or possibly absent vocabulary spurt (Rescorla et al., 2000). This could be because they need to accumulate more experience with words before learning them, resulting in a more gradual vocabulary growth without the logistic shape characteristic of the classic vocabulary spurt. Alternately, studies have found that children identified as late talkers can show a spurt as late as 32 months (Rescorla et al., 2000), and thus some participants may have shown a spurt after our data collection ended at age 30 months.

However, the prevalence of late talking is around 13% (Collisson et al., 2016); therefore, it is unlikely that all of the non-spurters in our sample were late talkers, and indeed many other infants showed a spurt in one language (typically their dominant language) but not the other. This suggests that infants may need sufficient experience in a language to show a spurt-like pattern as experience with particular words accumulates over a longer timeframe. Indeed, even amongst those children for whom we could identify a spurt, balanced bilinguals had a later and less steep spurt. Like late talkers, infants with less experience with a particular language might also show a vocabulary spurt later than 30 months, which would not have been detected in our study. Continuing data collection past 30 months, as well as directly measuring infants' absolute quantity of language exposure (rather than relative exposure as we did here; see Marchman et al., 2017) and the quality of language exposure (e.g., speech style and social context; see Ramírez-Esparza et al., 2014) could help to clarify our results and shed further light on how language exposure and individual differences relate to the vocabulary spurt.

Timing and Magnitude of the Vocabulary Spurt

Finally, our results provide new evidence regarding the timing and magnitude of the vocabulary spurt. We found that, on average, infants spurted at around 24 months of age, but some did so as early as 18 months while others did so as late as 29 months of age. Although there is overlap with the ranges reported in other studies (14 to 24 months in Silvén et al., 2014; 15 to 21 months in Kauschke & Hofmeister, 2002; around 20 months in D'Odorico et al., 2001), the identification of a vocabulary spurt at a later age in our study may be explained by the methodology we used, as we identified a spurt as the midpoint of the curve, which occurs after the first shoulder that is often identified as the spurt. Additionally, monolinguals spurted earlier (23 months on average) than bilinguals (25 months on average), therefore some variability can be attributed to each infant's language environment.

As for the magnitude, there was great variability for the words learned during the one-month period around the vocabulary spurt: infants learned as few as 8 words or as many as 174 words, with an average of 63 words across all vocabulary types. Our results indicated that infants who learned few words had rather low exposure to that language, and learned more words in their other language (i.e., during their spurt, bilingual infants learned an average of 57 words in their dominant language and 43 in their non-dominant language). Considering this difference in magnitude, the vocabulary spurt may vary from one child to another, and from one language to another for the same bilingual child. Specifically, a vocabulary spurt might be more noticeable in the dominant language than in the non-dominant language; a smaller or absent spurt in the non-dominant language may not be a cause for concern if an infant is developing typically in their dominant language. For the combined vocabularies, the number of concepts (22 - 126) and of words (26 - 174) learned during the spurt are in line with the study conducted on monolinguals by D'Odorico et al. (2001), who reported a range of 22 to 114 words in a month.

Strengths and Limitations

One of the main strengths of the present study is its longitudinal design and the number of data points collected: 14 times per participant on average (up to monthly). Although some studies have gathered expressive vocabulary data monthly (D'Odorico et al., 2001) or daily (Ganger & Brent, 2004), others have not sampled as densely (some children had as few as four data points in Frank et al., 2021; four time points in Kauschke & Hofmeister, 2002; bimonthly measures in Rescorla et al., 2000; four time points in Silvén et al., 2014). We used a strict inclusion criteria which limited our sample to infants who contributed dense data throughout the entire data collection period, and who were very unlikely to have already undergone a vocabulary spurt before data collection commenced. On one hand, this approach allowed us to identify vocabulary spurts with accuracy and confidence, but on the other hand this reduced our sample from a larger pool of 117 infants to 45 infants, which reduced statistical power. Additionally, we largely analyzed language exposure as a continuous variable, rather than categorical (i.e., monolingual vs. bilingual), which allowed us to evaluate the effects of language exposure on vocabulary acquisition more precisely. A limitation is that we did not measure cognitive skills that have previously been linked to the timing of the vocabulary spurt, such as fast mapping and categorization (Mervis & Bertrand, 1994; Poulin-Dubois et al., 1995). An interesting future direction might be to investigate whether vocabulary growth contributes the development of these skills (rather than the reverse as posited by cognitive theories), as has been observed for other phenomena such as word learning biases (Byers-Heinlein & Werker, 2013; Kalashnikova et al., 2016). Data from bilinguals would be valuable in evaluating this possibility.

As it has been the case in previous studies, a limitation of our study relates to the age range included. Studies have identified the vocabulary spurt as early as 14 months (Silvén et al., 2014) and as late as 32 months (Rescorla et al., 2000). While the 16 to 30 months range is not narrow, and we followed infants within the full age range of our vocabulary instrument (Boudreault et al., 2007; Marchman et al., 2023), it is possible that some infants underwent a vocabulary spurt before or after our data collection period, and therefore it was not captured here. Future studies should aim to follow participants starting at a younger age and ending when they are older.

Additionally, the measures used in the study are not without limitations. We measured language exposure using parent report, which has proven to be reliable for bilingual infants and congruent with measurements obtained from daylong home recordings (Orena et al., 2020). However, its reliability may be affected by different factors in the infant's environment, such as the number of family members who live in the household. Infants in our study were being raised in relatively small households (mostly composed of two main caregivers and the child participating in the study), however, this might not be the case in other bilingual samples. Future studies could assess language exposure using full-day audio recordings in more diverse samples, to capture the richness of exposure from multiple caregivers and larger households. We measured vocabulary via parental checklists, which have some limitations as they may show slight inaccuracies in vocabulary size. For example, the instrument's validity may be affected by whether one or more caregivers completed the questionnaire, and whether the same or different caregivers completed the instrument in each language (Marchman & Martínez-Sussmann, 2002). Also, parents may check some words that their child produced once and then stopped producing. Although parents received pre-filled out CDI forms with the information from their child's previous measurement, we note that parents in our study could and did uncheck words that their child no longer said.

Nonetheless, a strength of our study is that the logistic curve method is more robust to incidental parental report inaccuracies, as it considers an infant's entire trajectory instead of the increase from one measurement to another. Importantly, this method offers a more objective identification of a vocabulary spurt than the threshold approach (i.e., a certain number of words must be learned in a certain period of time). However, one limitation is that the curve's midpoint may not directly correspond to the month when infants were empirically reported to learn the most words. Additionally, we fit logistic curves to all infants, even though some trajectories might be well-described by a linear or quadratic curve (see Figure 1; Frank et al., 2021; Ganger & Brent, 2004), making the spurt less clear in these infants.

A final strength of the present study was its focus on bilinguals, as only one previous study had reported analyses relevant to the vocabulary spurt in this population (Silvén et al., 2014). It is nonetheless important to state that our sample of bilingual infants had relatively stable exposure to each language, and were growing up in a particular context where both languages enjoy a high status in the community and bilingualism is common. These findings may not generalize to bilinguals who experience large shifts in their language exposure, or those growing up in different contexts (e.g., in learning one majority and one minority language; Ramírez-Esparza et al., 2017).

Conclusion

This study provides new empirical evidence regarding the vocabulary spurt and shows support for accumulator models in explaining patterns of vocabulary acquisition. Results show how developmental trajectories may differ for infants from different language backgrounds (i.e., bilinguals vs. monolinguals), and the timing and the spurt can vary widely even for those from similar backgrounds. Moreover, our findings underscore that an absent or later spurt is not necessarily a signal of language delay, particularly in a bilingual child's non-dominant language.

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Appendices

Table A1 List of the packages used for the project and their version

Package	Version
cowplot	1.1.1
dplyr	1.1.3
drc	3.0-1
ez	4.4-0
forcats	1.0.0
ggplot2	3.4.3
ggpubr	0.6.0
gridExtra	2.3
janitor	2.2.0
jtools	2.2.2
kableExtra	1.3.4
lme4	1.1-34
lmerTest	3.1-3
lubridate	1.9.2
MASS	7.3-58.1
Matrix	1.6-1
performance	0.10.4
purrr	1.0.2
RColorBrewer	1.1-3
readr	2.1.4
rempsyc	0.1.5
report	0.5.7
sessioninfo	1.2.2
sjPlot	2.8.15
stringr	1.5.0
tibble	3.2.1
tidylog	1.0.2
tidyr	1.3.0
tidyverse	2.0.0

Appendix B: Robustness Checks

We conducted robustness checks to confirm that the results were not due to decisions made regarding the design of the procedure (i.e., missing data, including bilinguals and monolinguals in the sample) or the analyses (i.e., enter English and French in the same model, exclusion based on age at Time 1).

To account for bilingual's missing data in one language, we conducted robustness analyses excluding the timepoints where data was missing from the other language. Results from the robustness analyses are in line with those for the mixed-effects models for single-language, as they showed a statistically significant and negative effect of exposure percent on the midpoint (B = -.04, β = -.42, p = .003) and a positive and statistically non-significant effect on the slope (B = .00, β = .01, p = .912). In other words, infants with higher language exposure tend to show an earlier vocabulary spurt in that language and a steeper slope, although the latter was not significant.

To corroborate that results for single-language did not vary between English and French data, separate linear models were performed for each language as a robustness check. Results show similar negative effects (although non-significant, likely due to decreased sample size) of exposure percent on the midpoint in English (B = -.04, β = -.37, p = .119) and French (B = -.04, β = -.37, p = .065), as well as positive effects on the slope in English (B = .05, β = .32, p = .182) and French (B = .01, β = .06, p = .779). In other words, infants showed similar vocabulary acquisition trajectories in English and in French, and there were no differences across languages.

As an additional robustness check, we excluded strict monolinguals (i.e., infants exposed to more than 90% of only English or French) from the concept and word linear models. Results from the rest of the robustness analyses followed the same direction as the previous result, as exposure balance had a positive effect on the midpoint (concept: B = .02, β = .10, p = .682; word B = .05, β = .21, p = .410), and a negative effect on the slope (concept: B = -.02, β = -.10, p = .687; word: B = -.02, β = -.11, p = .657) but did not reach statistical significance; this may be due to the reduced sample size (concept n = 18, word n = 18).

Finally, we included in the analyses those infants who started data collection after 18 months of age, in case they showed a vocabulary spurt later than expected. The sample size without the Time 1 age restriction was 77 infants, and ultimately consisted of 62 infants who showed a vocabulary spurt in at least one vocabulary type. Robustness analyses showed results in line with those of the previous models. For single-language vocabulary, mixed-effects models showed a statistically significant and negative effect of exposure percent on the midpoint (B = -.04, β = -.38, p < .001) and a positive effect on the slope, which did not reach statistical significance as in the more controlled sample (B = .02, β = .16, p = .073). For the combined languages, exposure balance had a positive and statistically significant effect on the midpoint (concept: B = .04, β = .28, p = .035; word (B = .06, β = .37, p = .005). Exposure balance had a statistically significant and negative effect on the slope (concept: B = -.04, β = -.28, p = .037;

word: B = -.05, β = -.30, p = .025). Overall, robustness analyses confirm our main findings that infants with higher exposure to a particular language had an earlier vocabulary spurt in that language, and that more balanced bilinguals tended to have a later and less steep vocabulary spurt in their combined languages.