Bilingual Insights into the Initial Lexicon

The Role of Cognates in Word Acquisition

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A mamá, a papá, a Íñigo.

Acknowledgements

I am not the first to investigate language acquisition. Many have preceded me, and I hope many will follow—perhaps to the surprise of the reader, language acquisition remains unsolved at the conclusion of this research project. Though not the first one, I believe I have reasons to believe I have been the most privileged to do so. My privileges have often taken the form of people, and I want to spend some lines to appreciate their important role in the making if this dissertation.

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Abstract

Bilingual infants acquire words at a similar rate as monolinguals infants, despite facing a more complex linguistic environment. The mechanisms underlying this achievement are unclear. We investigated the possible role of cognateness—form-similarity across translation equivalents (TEs)—as a facilitator of bilingual lexical growth. We first modelled the acquisition trajectories of TEs, and found a facilitation effect of cognateness, only in the language of lower exposure. We provided a mechanistic account for this effect, rooted in the language non-selective hypothesis of lexical access. We then tested the plausibility of a central assumption in this account: that bilingual infants activate TEs in both languages in parallel, even during monolingual situations. We used a primed word recognition task in which participants were tested in exclusively one of their languages, while we covertly manipulated the cognateness of the prime words. Overall, we provide insights into the role of language non-selectivity in the initial bilingual lexicon.

Resum

Els infants bilingües adquireixen paraules a un ritme comparable als monolingües, malgrat una exposició a un entorn lingüístic més complex. En aquesta tesi, investiguem el paper de la cognasticitat (similitud en forma entre traduccions equivalents o TEs) com a facilitador de l'expansió del lèxic. El modelatge de les trajectòries d'adquisició de les TEs, ha mostrat un efecte de facilitació de la cognasticitat a la llengua amb menor exposició. El resultats s'expliquen a través de la hipòtesi de l'accés lèxic no selectiu. Mitjançant una tasca de reconeixement de paraules a la que es va manipular la cognasticitat de las paraules experimentals de manera encoberta, s'ha posat a prova el pressupòsit de que els infants bilingües activen les TEs en ambdues llengües simultàniament en situacions monolingües. Aquesta tesi aporta coneixements significatius sobre el paper de la no-selectivitat lingüística en el lèxic inicial.

Preface

Talking about *talking*—an activity sometimes referred to as *Linguistics*—is painfully difficult. Language is the most complex communicative system known, yet few people are surprised by the fact that infants pick it up so early in life, and so effortlessly. Some of those few intrigued people are developmentalists, whose scientific enterprise has kept a lucky bunch of them out of unemployment. For the last five years, I have been one of them. In this dissertation, I present some of the contributions that have resulted from these years.

We addressed the case of bilingual infants or infants being raised in two languages. In particular, we investigated how such dual language exposure impacts the emerge of a mental lexicon, where phonological and conceptual representations find each other. We focused on the case of bilingual language acquisition as an extension of the monolingual case, which may provide insights about how language acquisition is shaped by different experiences with language.

It is known to the developmentalist that the trajectories of language acquisition of different infants may diverge substantially. Some of the sources of this individual variability have been identified and are under investigation. Cross-linguistic differences is one of them. Infants learning two different languages may follow slightly different paths towards language acquisition. This is also the case for bilingual infants. An influential monograph by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) showed that the specific pair of languages that a bilingual child is learning affects their trajectories of vocabulary growth. In particular, they found that 24-month-old bilinguals were able to produce more words when their languages were lexically more similar (e.g., English-Dutch), compared to when both languages were lexically less similar (e.g., English-Mandarin). The motivation of this dissertation is to investigate the mechanisms underlying such facilitation effect.

The first goal of this dissertation was to provide a mechanistic explanation to the effect found by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018). We focused on the role of *cognates* (i.e., phonologically similar translation equivalents). We tested the hypothesis that cognate words are acquired earlier by children than non-cognate words. This would explain why participants in Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) who were learning lexically similar languages—sharing many cognates—had larger vocabulary sizes than those learning two languages with less lexical similarity—sharing fewer cognates. We first put forward the foundations of a model that involved the interaction between lexical frequency, quantitative language exposure, and cognateness, to generate a cognateness facilitation on word acquisition. We then designed a vocabulary questionnaire, the Barcelona Vocabulary Questionnaire (BVQ), which we used to collect vocabulary data from monolingual and bilingual participants living in the Metropolitan Area of Barcelona. These participants were learning Catalan and Spanish, two Romance languages that share high lexical similarity. We modelled comprehension and production estimates of a large sample of children to test the predictions of our model of word acquisition.

A second goal of this dissertation was to test the plausibility of a central assumption behind the model proposed in Chapter 2: that bilingual infants co-activate both languages during language exposure, even in monolingual situations. Previous studies had provided evidence in this direction, but had relied on paradigms in which participants were introduced into a bilingual environment while completing the task. We addressed this in Chapter 3. In collaboration with Prof. Kim Plunkett and Dr. Serene Siow, from the Universtity of Oxford, we designed an experimental task that would test the language non-selectivity of the developing bilingual lexicon in a purely monolingual context. For more than three years, we worked together, collecting data from a large cohort of monolinguals and bilinguals in both Oxford and Barcelona. Despite our efforts, methological complications kept us from being able to address the hypotheses of interest.

This was not the only setback we encounter during our research. The COVID-19 was an important set back for the project. First, it severely limited our access to participants for the experimental task in both locations. First, universities were completely shut down during the lock down imposed by the governments in both Spain and United Kingdom, meaning that access to laboratories was not possible, even for researchers. During these times, only online data collection could be conducted. Second, it became challenging to find participants, even after the lockdown was lifted. This was especially the case in Oxford, were bilingual participants were already hard to find. Some families did offer to us their time and interest, and took part in the testing sessions once the universities opened and the appropriate protocols were established. We are very grateful to them.

The timings and the aims of the project had to be adjusted to the circumstances. For instance, due to the tight schedule that we were left with after the lockdown, we decided to resume data collection in both laboratories in parallel. Initially, we planned to first conclude data collection in Oxford, were the original studies from which we adapted the experimental task were run. This would allow us to first replicate the original findings in the same population of monolinguals, making sure that the procedure would be an appropriate tool to test out hypotheses before moving to monolingual and bilingual infants in Barcelona. This was not possible. Unfortunately, we were unable to replicate the original findings, keeping us from drawing conclusions about our predictions in the experimental section of the present dissertation.

Despite the setbacks encountered during the collection and analysis of the experimental data in Chapter 3, I believe the present dissertation provides valuable insights into the early stages of the bilingual lexicon. In the discussion section, we elaborate on the these contributions, putting our thoretical proposal from Chapter 2, its assumptions, and its implications, in the center. We present this proporsal as the Accumulator Model of Bilingual Lexical Acquisition (AMBLA). We illustrate the rationale behind this model by simulating word acquisition trajectories that mirror the results obtained in Chapter 2. We conclude this dissertation with a discussion on future experimental and modelling work to follow the formalisation of AMBLA.

Throughout the preparation of this thesis, we put special attention into maximising transparency. The code used to run the experiments, and to collect and analyse the anonymised data, are accesible in the version-controlled GitHub repositories of their respective studies. I am aware that full computational reproducibility is not possible without a subtantial increase in the programming knowledge required from the reproducing researcher. I have made an effort to provide extensive documentation on the required steps for reproducing the analyses in this thesis. I have also made available a Docker image for each of the studies included in this dissertation. Opening this image should allow anyone to run the scripts in their local machine with all pre-installed dependencies in a relatively convenient way. Materials and results (e.g. heavy files, like model fits) are also available in the corresponding Open Science Framework repositories. The source code and materials used to write and render the present dissertation available in a stand-alone GitHub repository (https://github.com/gongcastro/thesis).

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1 Introduction

Most caregivers would be surprised to find that infants show signs of language comprehension as early as six months of age. There are indeed reasons to be surprised. The linguistic input presents infants with a fairly arbitrary set of sounds and visual cues, and the child faces the tasks of identifying which of them correspond to relevant linguistic units in their native language, and associating them to their corresponding referents. This task is far from trivial, yet infants succeed early in age, laying the foundations of am initial *mental lexicon*. In the present dissertation, we delve into early word acquisition through the lens of a particular case of language learner: the bilingual infant.

Bilingual infants are exposed to a dual linguistic input, which requires a number of computations that monolingual infants do not face. For instance, bilinguals learn two sets of words, one in each language, for the same set of concepts. An English-Spanish bilingual infant learns the words *cat* and *gato* for the same referent. Despite the increased complexity of their linguistic input, bilinguals do not fall behind their monolingual counterparts in their trajectories of vocabulary growth. The particular mechanisms that allow bilinguals to keep up with monolinguals are still unclear. In this dissertation, we investigate the possibility that bilinguals exploit *cognateness* (i.e., the phonological similarity between translation equivalents) to facilitate the acquisition of new words.

We consider the bilingual case as a natural extension of the monolingual case, which may provide insights about the early lexicon in both populations. For this reason, this introductory chapter (Chapter 1) begins with a brief summary of monolingual language acquisition during the first year of life, from early linguistic experience, to the shift from language-universal to language-specific perception abilities, and the formation of the first phonological representations of familiar word-forms. We then characterise the case of bilinguals, with an emphasis on the relationship between the dual linguistic exposure they receive, and their trajectories of lexical acquisition. We point out some unresolved questions concerning the impact of linguistic similarity on vocabulary growth, and recent suggestions of a facilitatory role of cognateness. Next, we discuss the *parallel activation* hypothesis of such facilitation effect, contextualised within the language non-selective account of the bilingual lexicon. Finally, we summarise the available evidence of language non-selectivity in the initial lexicon, and the methodological issues therein encountered. We conclude this chapter describing the aims and structure of the present dissertation.

1.1 The foundations of a lexicon

1.1.1 From speech sounds to lexical representations

Infants' earliest demonstrations of language familiarity trace back to their last weeks of pre-natal life. Hearing foetuses are exposed to auditory input from the 20th week of gestation (Eggermont & Moore, 2011), and start reacting to sounds between 24 and 36 weeks (DiPietro et al., 2013). From 36 weeks on, foetuses notice when the gestational parent is talking (DeCasper & Fifer, 1980; Kisilevsky et al., 2009; Voegtline et al., 2013), and can identify familiar melodies (DeCasper et al., 1994). At birth, infants' perceptual abilities are already tuned to pre-natal experience with language. Newborns can discriminate between linguistic and non-linguistic sounds (Ecklund-Flores & Turkewitz, 1996; May et al., 2018; Vouloumanos & Werker, 2004), and between their native language and non-native languages (Mehler et al., 1988; Moon et al., 1993). These early language discrimination abilities are shaped by infants' familiarity with some suprasegmental properties of the native language, namely prosody (Gervain, 2018). For instance, during the first two months of life, language discrimination is restricted to pairs of languages from different rhythm classes (Abboub et al., 2016; Byers-Heinlein et al., 2010; Cooper & Aslin, 1990; Mehler et al., 1988; Nazzi et al., 1998; Peña et al., 2003; Ramus et al., 1999, 2000). It is not until six months of age that infants use segmental information to discriminate between their native language and others. Before six months of age, infants discriminate between virtually any pair of phonemes (Aslin et al., 1981; Bertoncini et al., 1987, 1987; Eimas et al., 1971). Between six and 12 months of age (but see Zacharaki & Sebastian-Galles, 2022 for evidence at earlier ages), infants' perceptual abilities start tuning to the phoneme repertoire of their native language. By their first birthday, infants can only perceive phonemic contrasts present in their native language (Best, 1994; Kuhl, 1991; Kuhl et al., 2006; Segal et al., 2016; Werker & Tees, 1983; Werker & Tees, 1984).

As infants tune their speech perception abilities to the phoneme repertoire of their native language, they also start storing their first representations of familiar word-forms[1]. This task is not trivial, as young infants are rarely exposed to single-word utterances. Instead, infants' speech input mostly consists of utterances and other multi-word combinations, providing isolated words in rare occasions (e.g., Aslin et al., 1996). To identify word boundaries, infants rely on multiple mechanisms and cues available in the speech signal, like phonotactics (Friederici & Wessels, 1993; Friedrich & Friederici, 2005b; Jusczyk et al., 1994), phrase- and sentence-level

[1] Attempting to provide a clear definition of *word* goes beyond the aims of the present dissertation. We adhere to Jackendoff (2002)'s broad definition of *word* as a "finite list of structural elements that are available to be combined through a finite set of combinatorial principles, or *grammar*."

prosodic contours (Christophe & Dupoux, 1996; Gout et al., 2004; Jusczyk et al., 1992; Soderstrom et al., 2003), the predominant stress patterns of their native language (Cutler, 1990; Cutler & Norris, 1988; Thiessen & Saffran, 2007), or the statistical co-occurrence between syllables (Goodsitt et al., 1993; Saffran et al., 1996; Saffran, 2001). By the end of their first year, infants recognise familiar word-forms (Goodsitt et al., 1993; Hallé & de Boysson-Bardies, 1996; M. M. Vihman et al., 2004), even if embedded in continuous speech (Jusczyk & Aslin, 1995). These initial phonological representations are encoded in great phonetic detail: when infants are presented with subtle mispronunciations of known word-forms (e.g., one phonetic feature apart), they struggle to recognise them as familiar (Ballem & Plunkett, 2005; Mani & Plunkett, 2007; Swingley, 2005; Tamási et al., 2017). Being able to parse the speech stream into familiar word-forms is a critical milestone in early language acquisition: phonological representations of word-forms lay the foundations of an early lexicon.

The foundations of the lexicon are laid by the first associations between phonological representations of familiar word forms and their referents[2]. Evidence from inter-modal paradigms of word recognition (Delle Luche et al., 2015; Hirsh-Pasek & Golinkoff, 1996) shows that, by six months

[2]Although the role of the grammar in the early lexicon falls outside of the scope of the present dissertation, we acknowledge that grammatical information is incorporated in the lexicon, together with concepts and word-forms (Caramazza, 1997; Krauska & Lau, 2023), but we do not adhere to any particular account of way in which grammatical information may be encoded in the lexicon.

of age, infants are already forming their first lexical representations. For instance, Bergelson and Swingley (2012, 2015) presented pairs of familiar pictures to infants at different age points, from six to 20 months. In each trial, their caregiver named one of the pictures, participants' looking preference for the named picture was measured, and it was interpreted as a proxy of word recognition. Overall, the authors found evidence of target looking preference in all age groups, suggesting that word comprehension emerges from six months of age. This initial lexicon is sparse: according to parental reports of word acquisition in many languages, most infants barely understand more than 30 words before their first birthday (e.g., Bates et al., 1994; Fenson et al., 1994; Jackson-Maldonado et al., 1993; Kern, 2007). Early comprehension is usually associated with words of high lexical frequency, which refer mostly to people, interjections, body parts, colours and food (Campbell & Hall, 2022; Forbes & Plunkett, 2019; Frank et al., 2021; Marchman & Martínez-Sussmann, 2002; Parise & Csibra, 2012; Tardif et al., 2008; Tincoff & Jusczyk, 1999, 2012).

1.1.2 Vocabulary growth

During the second year of life, this initial lexicon undergoes rapid development, in quantitative and qualitative terms. Evidence for this is mostly provided by parental reports of vocabulary size across ages, collected using the MacArthur-Bates Communicative Development Inventory

(MCDI) (Bates et al., 1994; Fenson et al., 1994), or its adaptations to other languages and populations. This questionnaire includes a vocabulary checklist, which contains a list of words—generally between 400 and 600 words—to which caregivers respond if their child *Understands*, *Understand and Says*, or if the child does not understand or say the word. The response options may vary between versions and adaptations of the questionnaire, but the end product is generally the same: an estimate of participants' receptive (number of words the child *understands*) or productive (number of words the child *says*) vocabulary size, obtained by aggregating caregivers' responses across words in the vocabulary checklist. Despite the apparent subjectivity of parents' answers, estimates of vocabulary size produced by this questionnaire show moderate to high intra-participant reliability (Feldman et al., 2005; Frank et al., 2021; Reese & Read, 2000; Rescorla et al., 2005) and evidence of concurrent and predictive validity (e.g., in experimental settings, participants are more likely to successfully recognise auditory words which their caregivers have marked as acquired) (Bates & Goodman, 2013; Can et al., 2013; Dale, 1991; Jahn-Samilo et al., 2001; Pan et al., 2004; Robinson & Mervis, 1999; Swingley & Aslin, 2000; Werker et al., 2002).

Figure 1.1 illustrates how rapidly children's vocabulary grows during their second year of age. This figure shows receptive and productive vocabulary size norms available in the Wordbank database (Frank et al., 2017), which contains responses to the CDI by families of children learning many different languages across the world. We show vocabulary size norms for 51,800 monolingual children learning 35 distinct languages. As it can be seen in the figure, at 18 months of age, the average infant understands around 81 words and produces 42 words. At 24 months, they know around 243 words and produce 235 words. By 30 months, they understand around 507 words and produce 501 words. This rapid vocabulary growth, sometimes referred to as the *vocabulary spurt* (Bloom, 2002; Goldfield & Reznick, 1990), impacts infants' trajectories of word recognition (Fernald et al., 1998, 2013; Marchman & Fernald, 2008). Fernald et al. (1998) examined the speed at which 15-to-24-month-old infants looked at named target pictures, compared to distractor pictures. Although infants of all ages showed a looking preference for the target pictures—suggesting successful spoken word recognition—older infants did so faster. At 24 months, infants started directing their gaze towards the target picture before the offset of the spoken label (see also Swingley et al., 1999). At 15-months, infants shifted their gaze only after the end of the spoken label. Overall, these results suggest an improvement in the efficiency of spoken word recognition during the second year of life. The mechanisms behind this accelerated lexical acquisition and processing are still under debate (Bergelson, 2020; Bloom, 2002; McMurray, 2007; Tomasello, 2000).

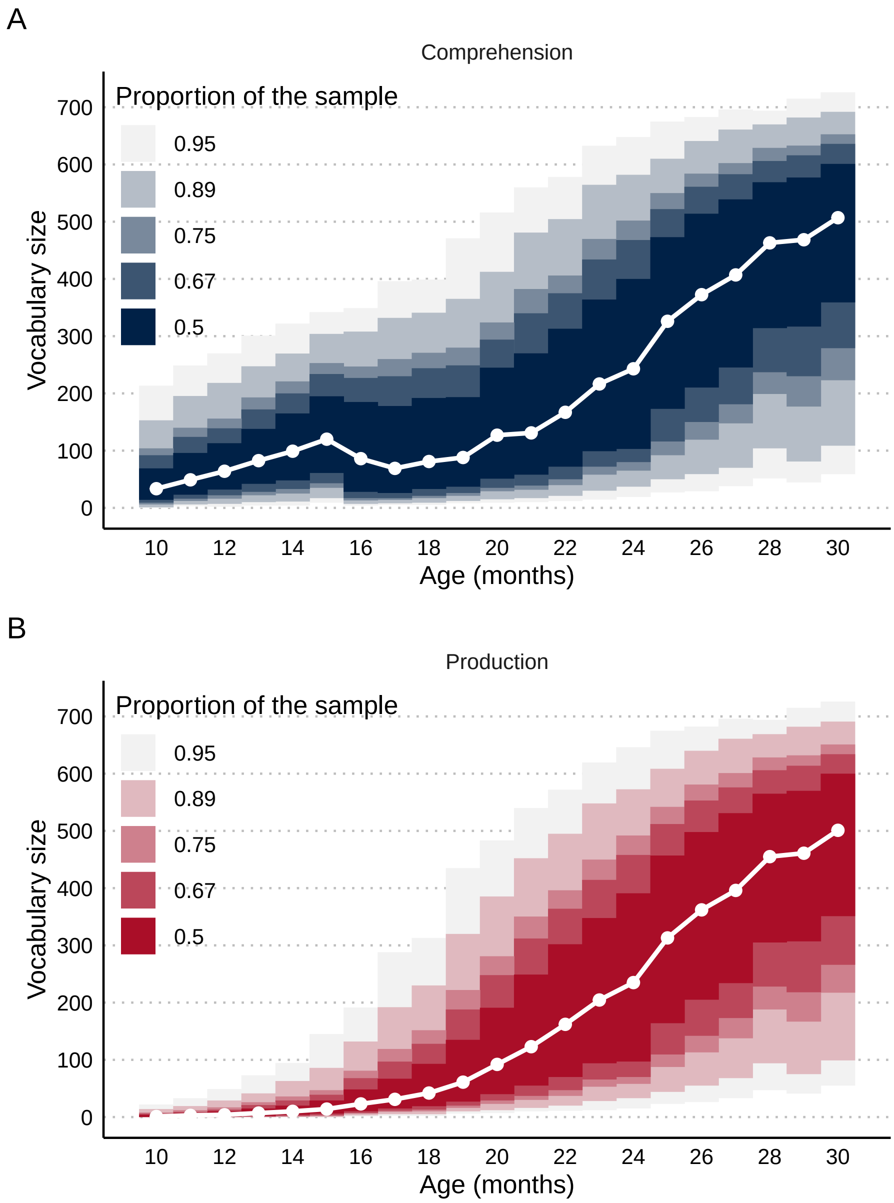

Figure 1.1: Wordbank norms for receptive (A) and productive (B) vocabulary size in monolingual children. Vocabulary sizes are expressed as the number of words that caregivers reported to be acquired by their child, either as *Understands* (receptive vocabulary) or *Undertands and Says* (productive vocabulary). Data were collapsed for each month of age. Median vocabulary sizes for each age group are indicated with white points and lines. Intervals of different width (depicted with shades of colour) contain different porportions of the sample.

1.1.3 Dynamics of early lexical access and selection

There is some consensus in that the initial lexicon is only different from the adult lexicon in quantitative terms. Many discontinuities and non-linearities in the performance of infants and adults in word recognition tasks can be explained as the result of differences in the size of the lexicon. For instance, evidence of *cascaded activation* in the developing lexicon emerges at around 21 months, associated with changes in the size of the lexicon. Cascaded accounts of lexical processing describe how activation spreads across representations at different levels in the lexicon, as the speech signal unfolds, and is one of the most defining features of the adult lexicon (Dell, 1986; Levelt, 1989). Most of these accounts assume, at least, three levels of representation: phonological, lexical, and semantic (Caramazza, 1997). Lexical representations embody associations between how words sound (*phonological representations*, or word-forms) and what words mean (*semantic representations*, or concepts). During word production and comprehension, representations from the three levels are activated (lexical access), and one of them is selected for comprehension or production (lexical selection). Which representations are activated across the three levels is determined by bottom-up and top-down sources of information. Figure 1.2 illustrates the dynamics in word comprehension.

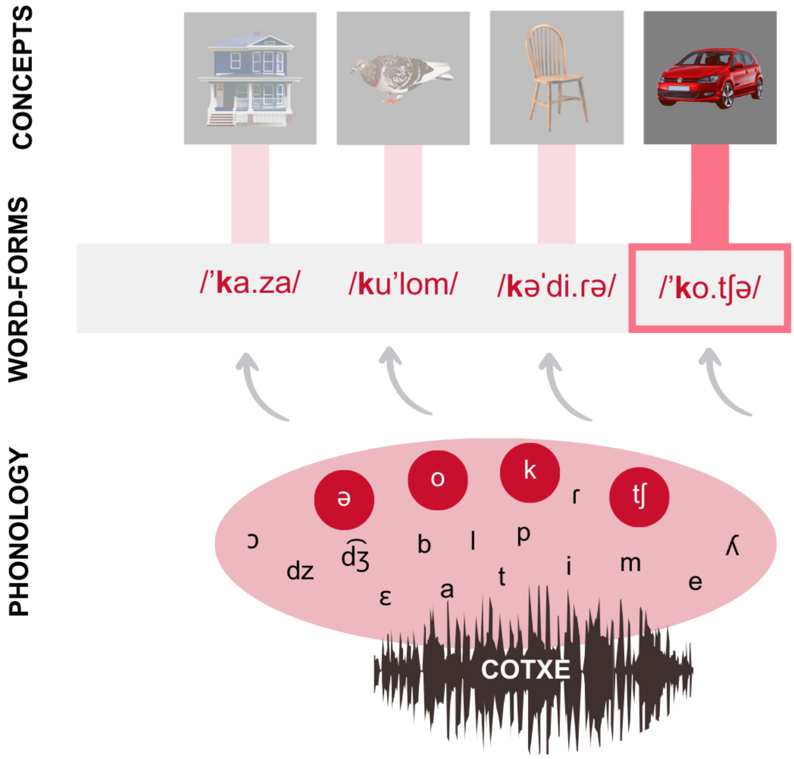

Figure 1.2: Lexical access and selection in the monolingual lexicon. The speech signal produced by a speaker uttering the Catalan word *COTXE* [car] activates phonological segments in the listener's mental lexicon. Activation then spreads across lexical representations containing such segments. In the illustration, a cohort of words also starting with phoneme /k/ is activated. The phonological form associated with the word *COTXE* receives the strongest activation, and is ultimately selected. In non-selected, but accessed, lexical representations, activation spreads also to the semantic layer, resulting in the activation of non-selected semantic representations. Note that, for simplicity, we have used phonemes to depict phonological units, but we acknowledge that phonological representations may be encoded at the lower level of phonetic features.

Spoken word recognition starts with the acoustic-phonetic processing of the speech signal. Phonological representations (e.g., articulatory features, syllables, stress patterns) in the listener's mental lexicon are activated according to how well they match the phonetic features and co-articulatory information in the speech stream. Lexical representations whose associated phonology matches the input are activated. The set of lexical candidates then is modulated by multiple factors: the degree of (mis)match with the unfolding acoustic input, the dynamics of competition between lexical candidates (Luce & Pisoni, 1998; McClelland & Elman, 1986; Norris, 1994), and top-down information like word frequency (Kukona et al., 2011), or grammatical, suprasegmental, and semantic constraints provided by the sentential context (Grosjean, 1980; W. Marslen-Wilson et al., 1988; Tyler & Wessels, 1983). Finally, the best-matching lexical representation is selected, and its associated meaning is activated for comprehension. This sequence of events occurs in a *cascaded* fashion. Activation spreads within and percolates across levels of representation while lexical selection is still ongoing. Lexical representations sharing phonological similarity (Grosjean, 1980; Luce et al., 1995; e.g., W. D. Marslen-Wilson, 1987; W. D. Marslen-Wilson & Welsh, 1978; McClelland & Elman, 1986) or semantic features (Collins & Loftus, 1975; Mirman & Magnuson, 2009; Neely, 1977) are co-activated, and semantic representations of activated lexical units are in turn retrieved, even if their associated lexical representation is ultimately not selected.

A clear proof of cascaded activation at the phonological and semantic levels was provided by Allopenna et al. (1998). The authors designed a word-recognition task in which (adult) participants were presented with four pictures on screen in each trial. Participants would then listen to a command sentence like “Pick up the *casket*; now put it below the diamond”, and perform the action. The authors manipulated the phonological relationship between the target object’s label (e.g., *casket*), and the label of each of the three distractors. Two of the distractors were phonologically related to the target, sharing onset (e.g., *castle*) or offset (e.g., *basket*), respectively. The other distractor was phonologically unrelated to the target (e.g., *nickel*). After the onset of the auditory target label, phonological distractors attracted participants’ eye fixations more than unrelated distractors. Distractors sharing phonological onset elicited the effect at an earlier time window than those sharing phonological offset. Such time course of distractor fixations suggests that the auditory presentation of the target label activated not only its (subsequently selected) phonological representation in participants’ lexicon, but also that of phonologically related representations. In summary, paradigms of spoken word recognition have proven useful in the investigation of the structure of the adult lexicon: phonological and semantic links between lexical representations are revealed as the phonological or semantic relationship between the stimuli is manipulated.

Priming paradigms of spoken word recognition have also provided strong support for the existence of phonological and semantic links between lexical representations before infants' second birthday. Arias-Trejo & Plunkett (2009) found that infants' spoken word recognition (e.g., *dog*) was interfered by the previous presentation of a semantically related word (e.g., *cat*). This effect was found in 21-month-olds, but not in 18 month-olds. Styles & Plunkett (2009) reported semantic priming in 24-month-old participants but not in 18 month-old participants. Earlier evidence of semantic priming has been provided by electrophysiological methods (Friedrich & Friederici, 2005a; e.g., Rämä et al., 2013). Even in the absence of visual referents, 24-month-old infants can tell when the words embedded in the speech stream are semantically related (Willits et al., 2013). Overall, effects of semantic relations in word recognition are observable in the initial lexicon.

Phonological priming effects also emerge from 18-months of age. Mani and Plunkett (2010, 2011a) developed an implicit naming task in which each trial started with the *silent* presentation of a prime picture. Then, a target-distractor picture pair was presented side-by-side. Finally, the target picture's label was presented auditorily. The authors manipulated the phonological overlap between the prime label and the target label, so that in half of the trials both labels were phonologically related, sharing phonological onset (*cat*-*cup*), or phonologically unrelated (*ball*-*comb*). Prime and target-distractor pairs were semantically unrelated. At 18 and 21 months of age, English monolingual infants showed different target looking preference patterns after phonologically related prime pictures, compared to after phonologically unrelated primes. This result suggests that infants implicitly named prime pictures—despite such pictures were presented in silence—and that the phonology of the resulting labels interacted with the subsequent auditory target recognition. The direction of the effect was different in both age groups. At 18 months, infants showed stronger target preferences after being previously presented with a phonologically related prime. But twenty-one month-olds' target preference was weaker after phonologically related primes, compared to after phonologically unrelated primes.

Mani & Plunkett (2011a) interpreted this shift from facilitation to inhibition as the consequence of the increase in vocabulary sizes of the older infants. The authors suggested that, in sparser lexicons, the fewer number of phonologically related lexical representations might have led to faster selection of the target word. In larger lexicons, lexical selection would be delayed by the cascaded activation of a larger number of phonologically related lexical representations. In support of this hypothesis, the authors found a positive significant correlation between the size of the interference effect in 21 month-old infants with two critical variables: participants' vocabulary size, and the size of the phonological cohort of the presented words. Results by Avila-Varela et al. (2021) provided converging evidence with German monolinguals: larger interference effects were found in participants with larger vocabulary sizes, even after controlling for age.

Chow et al. (2017) provided further evidence of the emergence of semantic *and* phonological links, and it association with lexical growth. The authors adapted the spoken word recognition paradigm by Huettig & McQueen (2007) to explore 24- to 30-month-old toddlers. In each trial, participants were presented with four pictures. Four seconds after, a word was auditorily presented. The authors analysed participants visual fixations to each picture after the auditory label was presented. In some trials, the auditory label referred to one of the pictures. In other trials, it did not refer to any of the pictures. In trials in which none of the pictures corresponded to the presented label, one of the pictures was a phonological distractor (its label shared phonological onset with the presented label). Another picture was a semantic distractor (its referent belonged to the same taxonomic category as the referent of the presented word). For instance, participants were presented with the pictures of a sandwich, a bus, a cat, and a dress. Then they would hear the carrier phrase “Look at the *bee*!”. The picture of the bus would be a phonological distractor (both words start with /b/), and the cat would be a semantic distractor (bees and cats are animals). Participants’ visual fixations revealed a preference for the phonological distractor at earlier stages of the post-naming phase, and a preference for the semantic distractor at later stages of the trial. These results are suggestive of a cascaded effect in spoken word recognition in toddlers, in which the presentation of the auditory word activated phonologically and semantically related lexical representations. Visual preference for the distractors was stronger in participants with larger vocabulary sizes, pointing to an association between the strength of the connections across related lexical representations and the growth of the lexicon.

In summary, previous studies on lexical access in monolingual toddlers support a cascaded activation account of lexical access during the first stages of lexical development, and point to a continuity between the initial lexicon and the adult lexicon, bridged through vocabulary growth during the second year of life.

1.2 Building a lexicon in two languages

1.2.1 Defining bilingualism

One may consider *bilingualism* a quite ill-defined term. In some studies participants are classified as bilinguals with very low exposure and command of a second language, while other studies require perfect, native-monolingual proficiency of both languages for a participant to be classified as bilingual. Since the present dissertation concerns simultaneous bilingualism in infancy, we identify bilingualism with dual language exposure. Quantitative language input is conventionally operationalised as the cumulative amount of time the infant has spent interacting with people who speak to them on a regular basis (e.g., parents, grandparents, siblings, daycare). In bilinguals, this linguistic input is divided into two languages, which may be spoken by the same of different people, at the same time or at different times.

Several instruments are available to measure language exposure in bilinguals, usually involving a semi-structured interview with the caregivers or detailed questionnaires that caregivers complete (e.g., Bosch & Sebastián-Gallés, 2001; Byers-Heinlein et al., 2020; Cattani et al., 2014; DeAnda et al., 2016; Orena et al., 2020). The end-product is generally a proportion of exposure to each of the languages, known as *Degree of Exposure* (DoE). The DoE reflects the cumulative amount of input that the child has received in one language, relative to the other. Although this measure is subject to biases and inaccuracies induced by the subjective judgement of caregivers, there is evidence of its external validity, as suggested by its high correlation with direct measures of infant-directed speech (Orena et al., 2020). The underlying assumption behind this measurement approach is that a child's linguistic experience can be quantified into a continuous measure of bilingualism. This score ranges from 0% exposure to a second language (monolinguals) to 50% (perfectly balanced exposure to both languages). The language exceeding 50% DoE is referred to as the *dominant* language of the child, and the other language is referred to as the *non-dominant* language. For methodological simplicity, some studies classify monolinguals and bilinguals into discrete categories. Although there is not a strict threshold to consider a child as bilingual, most studies consider a child as bilingual if they are exposed to a second language at least 20% of the time (Byers-Heinlein, 2015; Byers-Heinlein et al., 2021; Rocha-Hidalgo & Barr, 2023) (see Figure 1.3 for a visual illustration). This is the cut-off adopted in the present dissertation, whenever such classification into discrete groups is methodologically sound.

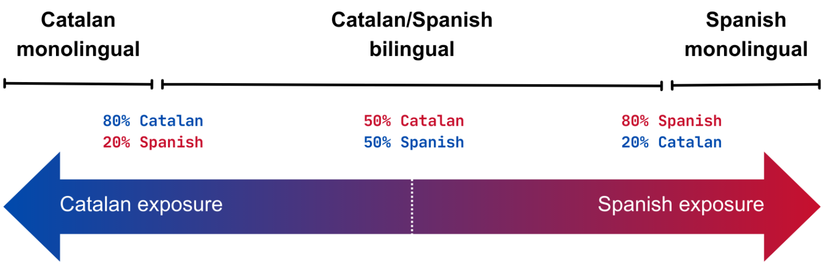

Figure 1.3: Visual illustration of the classification of participants dissertation into monolinguals and bilinguals in the present dissertation. Participants' relative exposure to Catalan and Spanish ranged from completely Catalan (in blue) to completely Spanish (in red). In agreement with the consensus in the firld, we classified participants into monolinguals and bilinguals by setting a threshold of 20% degree exposure to the language of least exposure. Participants with a relative exposure to a second language higher than 20% were classified as bilinguals, and as monolinguals otherwise.

1.2.2 Bilingual word acquisition

Bilinguals acquire language in a more challenging set of circumstances than monolinguals. First, there is little reason to think that bilinguals receive a larger amount of language exposure than their monolingual peers. Given that bilinguals' linguistic input is divided into two languages, they receive less exposure in each of their languages than monolinguals do. Second, bilinguals need to learn two codes, which might overlap to different degrees: two phonologies, two grammatical systems, and two lexicons. Third, the referential context in which bilinguals build a lexicon is also more complex. Bilinguals frequently learn at least two labels for the same referent, one for each language. The concepts behind both labels may not align perfectly. For instance, a child learning English and Spanish might learn the words *finger* and *dedo* (its Spanish translation). While both words might be used to refer to the same referent (e.g., the index *finger*), the word finger refers to eight appendices (four in each hand), whereas *dedos* refers to 20 appendices (five in each hand and five in each foot). In summary, bilinguals are presented with a more complex linguistic environment, facing additional demands compared to their monolingual counterparts.

Such increased cognitive demands do not keep bilinguals from reaching major language acquisition milestones at similar ages as monolinguals (see Sebastian-Galles & Santolin, 2020 for review), as observed in language discrimination (Bosch & Sebastián-Gallés, 1997, 2001; Byers-Heinlein et al., 2010; Nacar Garcia et al., 2018; Sebastián-Gallés et al., 2012; Weikum et al., 2007), discrimination of native phonemic contrasts (Albareda-Castellot et al., 2011; Bosch & Sebastián-Gallés, 2003; Burns et al., 2007; Sundara et al., 2006, 2008), or word-form segmentation (Antovich & Graf Estes, 2018; Bosch et al., 2013; Houston & Jusczyk, 2000; Hurtado et al., 2014;

Nazzi et al., 2006; Polka et al., 2002; A. S. M. Tsui et al., 2021). During the second year of age, bilinguals also undergo the same increase in vocabulary size that monolinguals go through (Core et al., 2013; Hoff et al., 2012; e.g., Pearson & Fernández, 1994). As in monolinguals, spoken word recognition becomes more efficient as the infant's lexicon expands (De Anda & Friend, 2020; DeAnda et al., 2018; Legacy et al., 2018; Poulin-Dubois et al., 2013, 2017). Such changes are modulated by the relative amount of input that the bilingual infant receives from each language. For instance, bilinguals acquire words faster, and become more efficient at spoken word recognition in their dominant language, compared to the non-dominant language (Cattani et al., 2014; Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al., 2018; Hoff, 2003; Marchman et al., 2010; Shneidman et al., 2013; Thordardottir, 2011). Overall, the monolingual and the bilingual lexicons grow at a similar rate, but some studies suggest that bilingualism may modulate word learning trajectories.

Hoff et al. (2012) collected vocabulary size data from a cohort of 103 infants at two age points at 22 and 30 months. Infants were being raised in English monolingual or English-Spanish bilingual homes in South Florida (United States). Both groups had equivalent socio-demographic backgrounds. Families of English monolingual infants filled in the MCDI, and families of English-Spanish bilinguals filled the MCDI and its Spanish adaptation, the *Inventario del Desarrollo de Habilidades Communicati-*

vas (Jackson-Maldonado et al., 1993). Monolinguals showed the largest English vocabulary sizes, followed by English-dominant bilinguals, and Spanish-dominant bilinguals. The reverse pattern was observed for Spanish vocabulary sizes. When Hoff et al. (2012) combined the vocabulary English and Spanish vocabulary sizes into a single measure of *total* vocabulary, monolinguals and bilinguals showed equivalent vocabulary sizes. These results indicate that bilinguals keep up with monolinguals in vocabulary growth (Bosch & Ramon-Casas, 2014; Byers-Heinlein et al., 2023; Core et al., 2013; see also Pearson et al., 1993; Pearson & Fernández, 1994; Poulin-Dubois et al., 2013), and highlight the importance of comparing monolingual and bilingual trajectories of lexical acquisition sizes taking both languages into account (Bedore et al., 2005).

Not all bilingual populations have shown equivalent patterns of lexical development. For instance, studies in other populations of bilinguals have reported differences in total vocabulary size in monolinguals and bilinguals, and equivalent conceptual vocabulary sizes. This suggests that bilinguals may acquire a larger number of words across both languages than monolinguals, corresponding to an equivalent number of lexicalised concepts in both groups (De Houwer et al., 2014; Siow et al., 2023), or even higher (Kern et al., 2019). These results suggest that the specific pair of languages that bilinguals learn must be taken into consideration when investigating the early stages of lexical development. Participants in Hoff et al. (2012) were learning English and Spanish. These two languages are relatively distant in typological terms. English is a Germanic language, while Spanish is a Romance language. In addition to their differences in grammar or phonology, English and Spanish also share fewer cognates than other pairs of languages like Italian and Spanish (Schepens et al., 2012). Recent studies have reported that bilingual learning two languages that share a higher amount of cognates may acquire words at a faster rate than those learning two languages sharing fewer cognates (Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al., 2018; Gampe et al., 2021). This might explain some of the variability observed in the characterisation of lexical growth across different bilingual populations.

1.3 Language non-selectivity in the bilingual lexicon

Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) conducted an impressive study of CDI responses were collected from a large sample of 372 bilinguals at 24-months of age. These bilinguals were learning English and an additional language—one of Bengali, Cantonese, Dutch, French, German, Greek, Hindi-Urdu, Italian, Mandarin, Polish, Portuguese, Spanish, and Welsh. Participants were raised in the United Kingdom, and English was the dominant language for most of them. Using an edit distance-based metric of similarity, the authors calculated the phonological similarity between the translation equivalents present in the English vocabulary checklist, and in the vocabulary checklist of each of the other languages. The average phonological similarity between English and each pair of languages was taken as a proxy to their lexical similarity. Some language pairs shared high lexical similarity (e.g., English-Dutch), while others shared very little (e.g., English-Mandarin). The authors then estimated the association between lexical similarity and participants' language outcomes—measured as their receptive and productive vocabulary size in English and the additional language—while adjusting for the influence of other predictors like age, sex, socio-economic status, and several properties of participants' speech input. Bilinguals' vocabulary size in the additional language showed a lexical similarity effect, in which children learning two lexically similar languages showed larger vocabulary sizes in the additional language, while English vocabulary did not show such association with lexical similarity. Overall, the results suggest that infants may benefit from the lexical similarity between their languages–particularly, by the presence of cognates—and therefore bilinguals' trajectories of word acquisition should be considered in the context of the pair of languages being learned.

A facilitation effect at the lexical level would have important consequences for infants learning highly similar languages. For intance, the relative typological distance between Catalan and Spanish is very small, especially at the lexical level. Both are Romance language, and share many cognates (i.e., form-similar translation equivalents). Figure 1.4 shows the overall lexical similarity between Catalan and Spanish, computed in the same way that Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) did. The lexical similarity between Catalan and Spanish is considerably larger than that of English and Dutch, the language pair with the highest similarity score in Floccia et al. This suggests that Catalan-Spanish bilinguals might be exposed to a substantially larger amount of cognates than bilinguals learning English and and additional language, like those in Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) and Hoff et al. (2012). If linguistic similarity, and especially lexical similarity, play a facilitative role in bilingual word acquisition, Catalan-Spanish bilinguals should show an even larger effect. This might explain why bilinguals in our database display larger vocabulary sizes than monolinguals, in contrast with the equivalent total vocabulary sizes reported by Hoff et al. (2012) in English-Spanish bilinguals (learning two languages sharing less lexical similarity).

The facilitation effect of lexical similarity on vocabulary growth reported by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) points to a possible cognateness facilitation effect on word acquisition, in which cognates are acquired at earlier ages than non-cognates. In this scenario, bilinguals

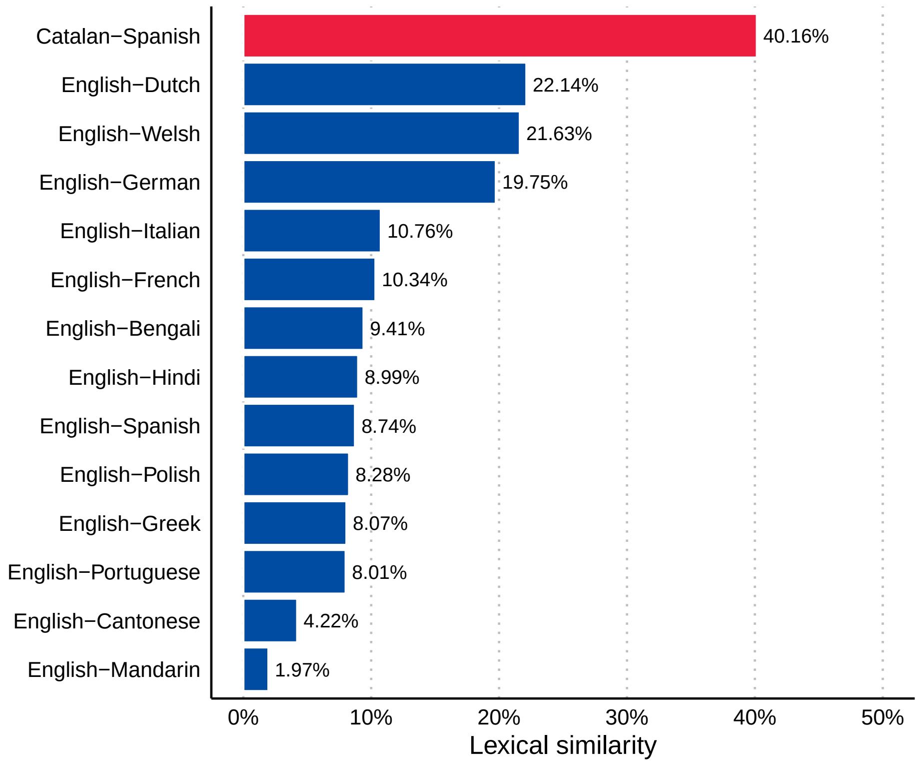

Figure 1.4: Lexical similarity between Catalan and Spanish, and between English and each of the additional languages in Floccia et al. (2018). We first obtained the broad phonological transcriptions of the words included in the Catalan and Spanish vocabulary checklists of the BVQ. Catalan words were transcribed to the Central Catalan variant (the most prevalent in the Metropolitan Area of Barcelona), and Spanish words were transcribed to Castilian Spanish. Interjections and onomatopoeic words were excluded. We then computed the normalised Levenshtein between each pair of translation equivalents, and averaged them.

learning languages that share more cognates would acquire words faster than those learning two languages that share fewer cognates. In line with this claim, previous studies had provided evidence in favour of an earlier age of acquisition for cognates. For instance, some studies have reported a larger proportion of cognates in bilinguals' lexicons than the proportion of non-cognates (Bosch & Ramon-Casas, 2014; Fabian, 2016; Schelletter, 2002). Other studies have found that bilinguals' performance in word recognition tasks is increased for cognate words, relative to non-cognate words (Gampe et al., 2018). More recent evidence in English-French bilingual suggest that cognates are may be more likely to be acquired than non-cognates at early ages (Mitchell et al., 2022). The specific mechanisms behind an earlier age of acquisition for cognates, however, are unclear.

To explain the facilitation effect of lexical similarity on vocabulary growth, Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) suggested that the *parallel activation* of cognates during language exposure might boost their acquisition. The notion of *parallel activation* stems from the language non-selective hypothesis of bilingual lexical processing. This hypothesis states that bilinguals co-activate lexical representations from both languages during language production and comprehension, even in monolingual situations. This parallel co-activation is the result of cascaded activation spreading across the two languages at multiple levels of word recognition and production. This hypothesis was initially proposed to account for different results in adult bilingual research.

Marian & Spivey (1999) presented Russian-English adult bilinguals with an cross-language interference task, divided in two blocks. In one block, participants would be presented with an instruction in English, like "Put the *marker* below the cross", after which two pictures were displayed on the screen. One depicted the target object (a stamp). The other depicted an object whose label in Russian shared phonetic features with the English target label (e.g., a stamp, *marka* in Russian). In the other block, the same procedure would be followed, but now with Russian as the target language. Participants were presented with the Russian instruction: "*Poloji* glaz *nije krestika*" [Put the *eye* below the cross]. The target picture would be an eye, and the distractor, a glove, whose English label shared phonetic features with the Russian target label. In both blocks, a control condition was run, in which target and distractor labels were phonetically unrelated. In line with Allopenna et al. (1998)'s results in monolingual adults, after hearing the target label, bilinguals fixated the cross-language phonological distractor significantly more than the unrelated distractors. These findings suggest that participants activated phonologically related word-forms in both Russian *and* English, which affected their overt visual exploration patterns during the task. In this case, parallel activation is driven by bottom-up activation of words in both languages through phonology, at a sub-lexical level. Words that sound the same in both languages are activated, and enter the cohort during lexical selection. Figure 1.5 illustrates this sequence of events.

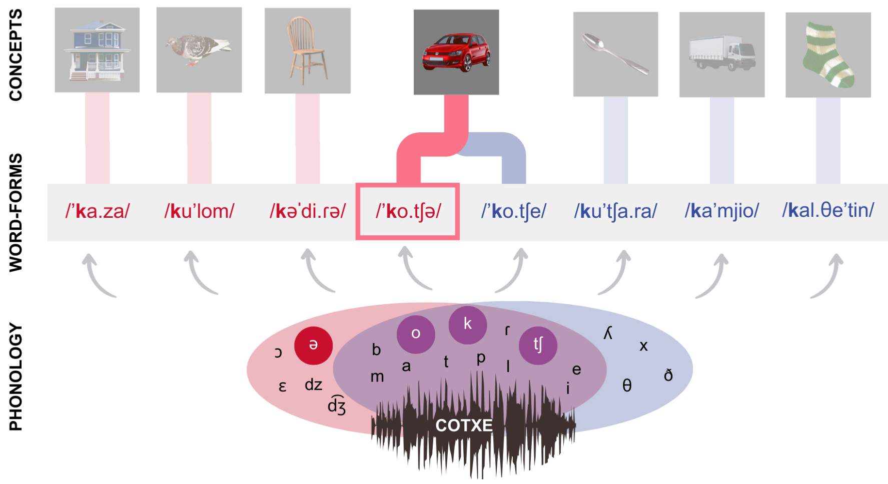

Figure 1.5: Lexical access and selection in the language-non selective bilingual lexicon. The speech signal produced by a speaker uttering the Catalan word *cotxe* [car] activates phonological segments in the repertoire of a Catalan-Spanish bilingual listener. Activation spreads across lexical representations in both languages that contains such segments. In the illustration, a cohort of words that also start with the /k/ phoneme are activated. The word-form associated with *cotxe* receives the strongest activation, and is ultimately selected. In non-selected, but accessed, lexical representations, activation percolates to the semantic layer, resulting in the activation of non-selected semantic representations.

Parallel activation can also be the result of cascaded activation spreading across lexical representations in both languages, through their shared semantic features. Previous studies have provided strong evidence of parallel activation in exclusively monolingual tasks by comparing the processing of cognates and non-cognates. In Costa et al. (2000), adult Catalan-Spanish bilinguals and Spanish monolinguals were asked to name pictures of common objects in Spanish. In half of the trials, the object labels were cognates in Catalan and Spanish (*sofà*-*sofá*, translations of *sofa*). In the other half of the trials labels were non-cognates (*taula*-*mesa*, translations of *table*). Bilinguals named cognate pictures faster than non-cognate pictures, even after adjusting for the lexical frequency of the items. Spanish monolinguals showed equivalent naming times for the two categories, as the distinction was meaningless to them. These results suggested that, in bilinguals, the Catalan phonnology was activated, facilitating Spanish word production: the visual recognition of the pictures led to the activation of their corresponding semantic representations, resulting in the cascaded activation of phonological representations in both languages.

In adults, the available evidence in favour of language non-selectivity in the bilingual lexicon is abundant across languages (Bobb et al., 2020; Colomé, 2001; Costa et al., 1999, 2000; Duñabeitia et al., 2009; Duyck, 2005; Hoshino & Kroll, 2008; Marian & Spivey, 2003; Spivey & Marian, 1999; Thierry & Wu, 2007), including sign languages (Giezen & Emmorey, 2016; Gimeno-Martínez et al., 2021; Van Heuven et al., 1998). Modelling efforts have successfully implemented formal accounts of the bilingual lexicon by incorporating cross-language interactions (Dijkstra et al., 2019; Dijkstra & Van Heuven, 2002; e.g., Kroll et al., 2010; Kroll & Stewart, 1994). In summary, there is consensus about the fact that bilinguals constantly co-activate both languages during word comprehension and production, even in fully monolingual situations.

Previous studies have provided evidence in of language non-selectivity in the initial bilingual lexicon (Bosma & Nota, 2020; Jardak & Byers-Heinlein, 2019; Poarch & Van Hell, 2012; Poulin-Dubois et al., 2013, 2017; Singh, 2014; Von Holzen et al., 2019; Von Holzen & Mani, 2012). Priming paradigms of word recognition tasks have been instrumental in this line of research. Using one of such paradigms, Von Holzen & Mani (2012) reported evidence of cross-language phonological priming in 21- to 42-months-old children learning German and English. At the beginning of each trial, the authors presented an auditory prime word in English. Then, the auditory target label was presented in German. Finally the target and distractor pictures were presented side-by-side. Participants' looking preference towards the target was recorded, and interpreted as a proxy of target word recognition. The authors manipulated the phonological overlap between the prime and target labels. In some trials, the English prime label and the German target label labels were phonologically related through translation: the prime label did *not* overlap with the target label in English (e.g., *leg*-*Stein* [*stone*]), but its translation in German did [*Bein*]. In the rest of the trials prime and target labels were phonologically unrelated in both languages. The authors found a stronger target picture looking preference in unrelated trials, compared to trials in the priming-through-translation condition. This suggests that participants activated the German translation of the auditory English prime word, and that this interfered with the recognition of the auditory German target word (which shared phonological similarity with the German translation).

Priming studies in which words from both languages are presented during the same experimental session or even within the same trial (Floccia et al., 2020; Jardak & Byers-Heinlein, 2019; Singh, 2014; e.g., Von Holzen & Mani, 2012) present an important methodological pitfall. In these tasks, participants are introduced in a bilingual context, in which the overall degree of activation of lexical representations in both languages may be artificially increased (Grosjean, 1997). This might have contributed, to some extent, to the strength of the parallel activation reported in these studies. It is possible that, in the daily life of a sizable amount of bilingual children, speech input in each language takes place at separate times and unlikely that they take place within the same communicative act. If this is the case, the practical relevance of language non-selectivity in vocabulary growth might be smaller than anticipated.

In summary, the parallel activation hypothesis suggested by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) to explain the cognateness facilitation effect relies on the language non-selectivity of the early lexicon. But experimental evidence in the developing lexicon for such language non-selectivity builds on experimental paradigms that may overestimate the amount of co-activation between the two languages, as they put participants in a bilingual context that might forcibly lead to both languages being active.

1.4 The present dissertation

The aim of this dissertation is to explore the impact of language non-selectivity on the developing bilingual lexicon, and its potential role in the facilitation effect of lexical similarity during vocabulary growth. In Chapter 2, we put forward an account of bilingual word acquisition, inspired in accumulator models of word language acquisition (Hidaka, 2013; Kachergis et al., 2022; McMurray, 2007; Mollica & Piantadosi, 2017). This model provides a mechanistic explanation for the facilitative effect of lexical similarity reported by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018). It describes an interplay between the lexical frequency of a word, the child's relative exposure to each language, and cross-language phonological similarity. In this model, bilinguals accumulate experience with words in one language, even when listening to words in the other language. We contrast this model against vocabulary data from bilinguals, collected using an *ad hoc* online questionnaire. This questionnaire was inspired in the CDI, adapted to the population of bilinguals learning Catalan and Spanish in the Metropolitan Area of Barcelona (Spain). We modelled the acquisition trajectories of 302 translation equivalents, testing the role of cognateness and its interaction with relative language exposure and lexical frequency with.

The predictions tested in Chapter 2 rely on the assumption that bilingual infants co-activate translation equivalents in both languages, even in monolingual situations. Although there is evidence in favour of cross-language activation in toddlers, as just said, previous studies have relied on experimental paradigms in which participants listen to words from both languages in each trials. This puts participants in a bilingual context in which parallel activation might result from an overall stronger activation of both languages induced by the experimental task, and not because of regular cascaded activation across languages. In Chapter 3, adapting the implicit naming paradigm by Mani and Plunkett (2010, 2011a) we test parallel activation in an exclusively monolingual task. As described in the Methods section of Chapter 2, this paradigm is a word recognition task in which priming stimuli are pictures presented in silence. Previous studies shown that infants at 18 months and older lexicalise pictures presented in silence (Duta et al., 2012; Mani & Plunkett, 2010, 2011a; Styles et al., 2015). In particular, Mani and Plunkett (2010, 2011a) found that word recognition is influenced by the prior presentation of a picture whose associated label is phonologically related to the target word. By manipulating the cognate status of the label associated with the prime image, we tested parallel activation in bilingual toddlers while avoiding the presentation of words in both languages.

The final chapter of this dissertation provides a summary of the findings of Chapter 2 and Chapter 3. We discuss their implications for the current understanding of the initial lexicon, and of how bilingualism shapes infants' trajectories of word acquisition.

2 Chapter 2

Note

This Chapter has been published as a pre-print:

Garcia-Castro, G., Avila-Varela, D., Castillejo, I., & Sebastian-Galles, N. (2023). Cognate beginnings to bilingual lexical acquisition. https://doi.org/10.31234/osf.io/dxsmz

2.1 Introduction

The foundations of word learning are in place at an early age. At six months, infants start directing their gaze to objects when hearing their labels (Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 1999), and shortly after caregivers start reporting some words as acquired by their infant in vocabulary checklists (e.g., Fenson et al., 2007; Samuelson, 2021). Most research on early word acquisition relies extensively on data from monolingual children, and is oblivious to the fact that a substantial proportion of the world population acquires more than one language from early ages (Grosjean, 2021). Previous work on bilingual vocabulary acquisition pointed to bilingual toddlers knowing, on average, less words in each of their languages than their monolinguals peers, and to both groups knowing a similar number of words—if not more words—when the bilinguals' two languages are pooled together. Hoff et al. (2012) found that English-Spanish bilingual toddlers in South Florida (United States) knew less words in English than monolinguals did, but both groups knew a similar total amount of words when both English and Spanish vocabularies were counted together. Other studies have provided converging evidence that bilinguals know a similar or even larger number of words than monolinguals when the two languages are aggregated (Gonzalez-Barrero et al., 2020; Oller & Eilers, 2002; Patterson, 2004; Patterson & Pearson, 2004; Pearson & Fernández, 1994; Smithson et al., 2014). A more detailed analysis of the words in bilinguals' lexicons shows some interesting patterns.

One important observation of studies on bilinguals' early vocabulary acquisition is that cognate words are easier to acquire than non-cognate words. Cognate words are translation equivalents that are phonologically similar (or share some type of form-similarity). For instance, the Spanish translation equivalent of cat is *gato*, a cognate word; the translation equivalent of dog is *perro*, a non-cognate word. For historical reasons, some pairs of languages share more cognates than others: languages typologically close (like Dutch and English or Italian and Spanish) share more cognates than languages typologically distant (like English and Chinese, or Urdu and Spanish). The conclusion that cognate words are easier to learn is based on two types of evidence: studies investigating vocabulary sizes in children learning language pairs with different percentages of cognates (that is, differing in their typological distance) and studies comparing the number of cognate and non-cognate words children know in a specific language pair.

Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) published an impressive study comparing vocabularies of children learning several language pairs differing in their percentage of cognates. The authors collected vocabulary data on word comprehension and production from 372 24-month-old bilingual toddlers living in the United Kingdom who were learning English and an additional language. The additional language was one of 13 typologically diverse languages: Bengali, Cantonese Chinese, Dutch, French, German, Greek, Hindi or Urdu, Italian, Mandarin Chinese, Polish, Portuguese, Spanish, and Welsh. The authors calculated the average lexical overlap between the words in each of these additional languages and their translation equivalents in English. Lexical overlap was calculated in terms of phonological similarity (described below) and it was taken as a proxy of the degree of cognateness between each pair of languages. Floccia and co-workers reported an increase in vocabulary size in the additional language (i.e., not

English) associated with an increase in the average phonological similarity between the translation equivalents of each language pair. For example, English-Dutch bilinguals (languages with a high phonological overlap), were able to produce more Dutch words than English-Mandarin bilinguals (languages with a low phonological overlap) were able to produce in Mandarin. Blom et al. (2020), Bosma et al. (2019), and Gampe et al. (2021) reported similar results, providing converging evidence of a facilitatory effect of a lower language distance (i.e., higher degree of cognateness) on vocabulary size.

A second set of studies suggested that cognates are overrepresented in bilinguals' early lexicon. Bosch & Ramon-Casas (2014) collected parental reports of expressive vocabulary from 48 Catalan-Spanish bilinguals aged 18 months and found that cognates represented a larger proportion of vocabulary than non-cognates. Schelletter (2002) provided converging evidence from a longitudinal single-case study, in which an English-German bilingual child produced cognates earlier than non-cognates, on average. But the high proportion of cognates in the vocabulary of the participants in these two studies may not necessarily evidence of a facilitation effect of cognateness, but rather of simply the high proportion of cognates present in the pair of languages being learned. For instance, if two given languages share a high proportion of cognates like 70%, the vocabulary contents of children learning both languages should, in principle, approximate such proportion of cognates, even in the absence of a cognateness facilitation effect. More recently, Mitchell et al. (2022) addressed this issue in a longitudinal study. The authors collected expressive vocabulary data of 47 16- to 30-month-old French-English bilinguals living in Canada, in both languages. They created two lists of translation equivalents; one made of 131 cognates, and one made of 406 non-cognates. Across ages, the proportion of words that children were reportedly able to produce was higher in the cognate lists than in the non-cognate list. Critically, this difference persisted after both lists were matched in size, controlling their semantic category (i.e., furniture, animals, food were similarity represented in both lists) and age-of-acquisition norms (an index of word difficulty). Taken together, the results of these two lines of research support the hypothesis that phonological similarity (as reflected in cognateness) plays a facilitation role in bilingual word learning.

Parallel activation of bilinguals' lexicons has been proposed as the underlying mechanism for such facilitatory effect (e.g., Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al., 2018; Mitchell et al., 2022). The parallel activation hypothesis stems from the language non-selective account of lexical access, which suggests that bilinguals activate both languages simultaneously during language processing, even in fully monolingual contexts. Evidence with adult bilinguals supporting the language-non selective account of lexical access has been reported for language comprehension and production, across the auditory and visual (reading and signing) modalities (Gimeno-Martínez et al., 2021; Hoshino & Kroll, 2008; Morford et al., 2011; Shook & Marian, 2012; Spivey & Marian, 1999; see Kroll & Ma, 2017 for review). One of the clearest pieces of evidence of parallel activation was provided by Costa et al. (2000). In this study, Spanish monolinguals and Catalan-Spanish bilingual adults were asked to name pictures of common objects in Spanish. In half of the trials, the object labels were cognates in Spanish and Catalan (árbol-arbre, translations of tree), whereas in the other half of the trial labels were non-cognates (mesa-taula, translations of table). Obviously, such distinction was only relevant for bilinguals. Bilinguals named cognate pictures faster than non-cognate pictures, even after adjusting for the lexical frequency of the items. In contrast, Spanish monolinguals, who were unfamiliar with the Catalan translations of the Spanish words they uttered, showed equivalent naming times for the two types of stimuli. The authors interpreted the difference between cognates and non-cognates in bilinguals as reflecting the additional phonological activation that cognate words would receive from their translation equivalents (due to language non-selective activation of bilinguals' lexicons). These results showed that bilinguals' Catalan phonology was activated during the production of Spanish words, facilitating the naming of cognate pictures. More recently, evidence of parallel activation has been reported in bilingual toddlers and children too (Bosma & Nota, 2020; Floccia et al., 2020; Poarch & Van Hell, 2012; Poulin-Dubois et al., 2013; Von Holzen et al., 2019; Von Holzen & Mani, 2012). Although there is a consensus on the role of parallel activation in bilinguals' lexical processing and acquisition, previous studies do not address its influence on the learning trajectories of individual words. Results are aggregated across words and provide no information about the specific dynamics of how parallel activation influences word learning. This is the goal of the present research.

We propose an account in which a learning instance for a word may also represent a learning instance for its translation equivalent, to the extent that such translation equivalent is co-activated. We use the term learning instance in the fashion of accumulator models of language acquisition; as an exposure to a word-form that constitutes an opportunity for the child to accumulate information about the word. We do not assume if a learning instance is a discrete or a continuous unit of accumulation of information. We consider that a learning instance of a word is an exposure to its (phonological) form if the resulting strength of activation of its representation in the child's lexicon reaches some thoretical threshold that leads to word-form recognition. This activation may result from the infant being exposed to the actual word-form, or the result of activation spreading through phonological or semantic links across lexical representation, as in the case of parallel activation. The strength of this co-activation is proportional to the phonological similarity between the two translation equivalents; given that cognates share higher phonological similarity than non-cognates, the former should be co-activated more strongly than the latter. This should lead to a faster accumulation of learning instances for cognates, compared to non-cognates. Parallel activation would allow bilingual children to accumulate learning instances for words in both languages even during fully monolingual situations, but the impact of this mechanism would be asymmetric across languages: words from the lower-exposure language would receive stronger activation from words in the higher-exposure language than vice versa. Therefore, the acquisition of words from the lower-exposure language would benefit more strongly from their cognate status than the acquisition of words from the higher-exposure language. This asymmetric cross-language activation would be consistent with previous reports of larger priming effects from the dominant to the non-dominant language (e.g., Grainger, 1998).

Consider the example of the Catalan-Spanish cognate translation equivalent /ˈgat/–/ˈga.to/ [cat], which are phonologically very similar. When the child listens to /ˈgat/, they will strongly co-activate /ˈga.to/ in parallel. If the child has already formed a form-meaning association for both word-forms, parallel activation may result from the activation of their common concept or from activation spreading through phonological similarity. We assume semantic co-activation to be constant across cognate and non-cognate translation equivalents, and focus on phonological co-activation as an additional source of activation that affects cognates more strongly than non-cognates. Therefore, this exposure will count as a learning instance for both co-activated forms. The case of the non-cognate translation equivalent /ˈgos/–/ˈpe.ro/ [dog] would be different. Given the low phonological similarity between both word-forms, an exposure to* ˈgos will result in a weak activation of /ˈpe.ro/ leading to such exposure counting as a learning instance for /ˈgos/ (which the child was exposed to), but not for /ˈpe.ro/. While /ˈgat/–/ˈga.to/ will benefit from phonological co-activation, /ˈgos–ˈpe.ro/ will not. If the child receives linguistic input from one of the languages more often than from the other, this effect might affect each form of the cognate translation equivalent differently. For instance, if the child receives a larger amount of Catalan input than Spanish input, they will encounter the Catalan form /ˈgat/ more frequently than the Spanish form /ˈga.to/. Through parallel activation, /ˈgat/ will activate /ˈga.to/ more often than vice versa. Ultimately, /ˈga.to/ will benefit more strongly from its cognate status than /ˈgat/, as it receives additional learning instances from its translation equivalent more often than /ˈgat/.

To test these predictions, we collected vocabulary data on production and comprehension from a large sample of bilingual Catalan-Spanish children. We adopted a Bayesian explanatory item response theory approach to model the probability of acquisition of 604 Catalan and Spanish nouns included in the vocabulary checklist. Words were considered as acquired if caregivers reported such word to be understood (comprehension) or understood and said (production) by their child. We estimated the impact of several predictors of interest on the probability of acquisition, including participants' age and rate of exposure to the word-form, and the cognate status of the word-form. As described in the Methods section, rate of exposure was a composite measure taking into account participant' language exposure and word's lexical frequency. We predicted an interaction between cognate status and word-form exposure rate in which the probability of comprehension is higher for low-exposure cognate words, but not for high-exposure cognate words.

2.2 Methods

All materials, data, and reproducible code can be found at the OSF (https://osf.io/hy984/) and GitHub (https://github.com/gongcastro/cognate-beginnings) repositories. For reproducibility, a Docker image of the RStudio session is available on DockerHub (https://hub.docker.com/repository/docker/gongcastro/cognate-beginnings/). This study was conducted according to guidelines laid down in the Declaration of Helsinki, and was approved by the Drug Research Ethical Committee (CEIm) of the IMIM Parc de Salut Mar, reference 2020/9080/I.

2.2.1 Questionnaire

To collect vocabulary data from participants, we created an ad hoc questionnaire: the Barcelona Vocabulary Questionnaire (BVQ) (Garcia-Castro et al., 2023). This questionnaire was inspired by the MacArthur-Bates

Communicative Development Inventory (Fenson et al., 2007) and its adaptations to other languages, and was implemented on-line using the `formr` platform (Arslan et al., 2020). This questionnaire is structured in three blocks: (1) a language exposure questionnaire, (2) a demographic survey, and (3) two vocabulary checklists. Vocabulary checklists followed a similar structure as the Oxford Communicative Developmental Inventory (Hamilton et al., 2000) and consisted of two lists of words, one in Catalan and one in Spanish. Both lists included items from a diverse sample of 26 semantic or functional categories. The Catalan checklist contained 793 items and the Spanish checklist contained 797. Items in one language were translation equivalents of the items in the other language (e.g., the same participant responded to both *gos* and *perro*, Catalan and Spanish for dog), roughly following a one-to-one mapping. Some of the words in Catalan did not have a clear translation or had more than one possible translation in Spanish, and vice versa, therefore the unequal number of words included in the two lists.

Table 2.1: Summary of the items included in the final analyses.

Semantic category	List A	List B	List C	List D	Examples
Household items	31	26	30	25	tray, shower, syrup, radio, telephone
Food and drink	29	26	23	27	ice, pasta, potato, applesauce, watermelon
Animals	26	23	19	25	giraffe, parrot, fly (animal), penguin, rat
Outside	14	13	13	15	party, rain, shovel, pool, store
Body parts	14	12	11	11	face, finger, beard, eyebrow, tooth
Toys	11	11	12	13	book, goal, paper, painting, rake (object)
Clothes	12	12	10	10	zipper, sandal, scarf, belt, skirt
Vehicles	9	10	11	10	trolley, helicopter, tractor, ambulance, subway
Colours	6	6	6	6	blue, white, black, red, green
People	7	4	6	6	grandma, teacher, doctor, cousin, aunt
Furniture and rooms	4	4	4	4	bath, kitchen, corridor, terrace
Time	2	2	2	2	day, night
Adventures	1	1	1	1	witch
Parts of things	1	1	1	1	wheel
N	167	151	149	156	-

For each word included in the vocabulary checklists, we asked parents to report whether their child was able to understand it, understand and say it, or did not understand or say it (checked out by default). Given the large number of words in the vocabulary checklists, we created four different subsets of the complete list of items (A, B, C, and D) Each subset contained a random but representative sub-sample of the items from the complete list (see Table 2.1). Semantic or functional categories with less than 16 items—thus resulting in less than four items after dividing it in four subsets—were not divided: all of their items were included in the four subsets. Items that were part of the trial lists of some ongoing experiments in the lab were also included in all versions. The resulting reduced list contained between 343 and 349 Catalan words, and between 349 and 371 Spanish words.

To compute predictors of interest, we manually generated a broad phonological transcription of every word included in the vocabulary checklists in X-SAMPA format (Wells, 1995). Catalan word-forms were transcribed to Central Catalan phonology, and Spanish word-forms were transcribed to Castilian Spanish phonology.

2.2.2 Participants

We collected 436 questionnaire responses from 366 distinct children (175 female, 179 male, 12 not reported, mainly White). Participants were aged 12-32 months (*M* = 22.23, *SD* = 4.88, *Range* = 12.06–31.93). Of those participants, four participated four times, eight participated three times, 42 participated twice, and 312 participated once. Recurrent participants provided responses with a minimum of 25 days between responses, and a maximum of 527 days. Participants were randomly allocated into one of the four questionnaire subsets (A, B, C, or D). Each participant was always allocated to the same subset.

Participants were residents in the Metropolitan Area of Barcelona (Catalonia, Spain). Data collection took place between March 30th, 2020 and October 31th, 2022. Participants were part of the database of the Laboratori de Recerca en Infància at the Universitat Pompeu Fabra, and were contacted by e-mail or phone if their child was aged between 12 and 32 months, and had not been reported to be exposed more than 10% of the time to a language other than Spanish or Catalan (see Table 3.1 for a more detailed description of the sample). In total, 70 participants (16.06%) participants were reported to be exposed in less than 10% to a third language other than Catalan and Spanish. All families provided informed consent before participating. Upon consent, families were sent a link to the questionnaire via e-mail, which they filled from a computer, laptop, or mobile device. Filling the questionnaire took 30 minutes approximately. After completion, families were rewarded with a token of appreciation.

We used the highest self-reported educational attainment of parents or caregivers as a proxy of participants' socio-economic status (SES). This information was provided by each parent or caregiver by selecting one of six possible alternatives in line with the current educational system in Spain: *sense escolaritzar/sin escolarizar* [no education], *educació primària/educación primaria* [primary school], *educació secundària/educación secundaria* [secondary school], *batxillerat/bachillerato* [complementary studies/high school], *cicles formatius/ciclos formativos* [vocational training], and *educació universitària/educación universitaria* [university degree]. Most families reported university studies (356, 82%), followed by families where the highest educational attainment were vocational studies (59, 14%), secondary education (8, 2%), complementary studies (6, 1%), primary education (1, <1%), and no formal education (2, <1%).

Table 2.2: Participant sample size by age and degree of exposure to Catalan. For participants exposed to Catalan and Spanish exclusively, the proportion of Catalan exposure shown in the table is complementary to the degree of exposue to Spanish. For participants exposed to a third languages this proportion is not complementary unless one adds the degree of exposed to the third language, which never exceeded 10%. Participants with 100%, 0%, and 50% Catalan exposure would be traditionaly classified as Catalan monolingual, Spanish monolingual, and Catalan-Spanish bilingual, respectively.

	Age (months)					
Catalan exposure	[10-14]	(14, 18]	(18, 22]	(22-26]	(26-30]	(30-34]
75-100%	18	23	36	38	20	7
50-75%	8	13	30	41	18	1
25-50%	10	17	45	29	17	0
0-25%	7	11	21	17	8	1
\textit{N}	43	64	132	125	63	9

2.2.3 Data analysis

2.2.3.1 Data processing

We collected data for 1,590 words. We restricted the analyses to responses to nouns (628 items corresponding to other grammatical classes were excluded). We then excluded items with missing lexical frequency scores (n = 268, see Model predictors section), items that included more than one lemma (e.g., *mono/mico* [monkey], n = 47), multi-word items or phrases (e.g., *barrita de cereales* [cereal bar], n = 9). Finally, we removed items without a translation in the other language (n = 32). This resulted in a final list of 606 items, corresponding to 303 Catalan words and their 303 Spanish translations (302 translation equivalents). After collecting participants' responses, the final dataset consisted of 138,078 observations, each corresponding to a single response of one participant to one item. Each translation equivalent received a median of 234 responses (*Range* = 106–872) from participants, both languages pooled together. Data processing and visualisation was done in R (R Core Team, 2013, version 4.2.2).

2.2.3.2 Modelling approach

We modelled the probability of participants answering each response category (*No* < *Understands* < *Understands and Says*) using a Bayesian, multilevel, ordinal regression model. This model allowed us to estimate both item and participant word-acquisition trajectories, while estimating the effect of our variables of interest: *Age* (number of months elapsed between participants' birth date and questionnaire completion), *Length* (number of phonemes in the X-SAMPA phonological transcription of the word-form), *Exposure* (a language exposure-weighted lexical frequency score), and *Cognateness* (defined as the phonological similarity between translation equivalents). A more detailed descriptions of these predictors is provided in Section 2.2.3.3. We added these variables as main effects, together with the two-way and three-way interactions between *Age*, *Exposure*, and *Cognateness*. Participant-level and item-level random intercepts and slopes were included where appropriate, according to the structure of the data (Barr et al., 2013). We specified a weakly informative prior around the parameters of the model. Equation 3.2 shows a detailed description of the model. See Section 2.5 for a detailed description of the model and its diagnostics.

We implemented the model using `brms` (Bürkner, 2017), an R interface to the Stan probabilistic language (2.32.1) (Carpenter et al., 2017). We ran four iteration chains using the by-default No U-Turn Sampler algorithm with 1,000 iterations each and an additional 1,000 warm-up iterations per chain.

$$
\begin{aligned}
&\textbf{Response } (k) \textbf{ to word } i \textbf{ by participant } j\\
\text{Response}_{ij} &\sim \text{Cumulative logit}(\theta_{k_{ij}})\\
&\text{where } k \in \{\text{No} \rightarrow \text{Understands}, \text{Understands} \rightarrow \text{Understands and Says}\}\\
&\textbf{Distribution parameters}\\
\theta_{k_{ij}} &= (\beta_{0_k} + u_{0_{i_k}} + w_{0_{j_k}}) + (\beta_1 + u_{1_i} + w_{1_j}) \cdot \text{Age}_i +\\
&(\beta_2 + u_{2_i} + w_{2_j}) \cdot \text{Length}_{ij} + (\beta_3 + u_{3_i} + w_{3_j}) \cdot \text{Exposure}_{ij} +\\
&(\beta_4 + u_{4_i}) \cdot \text{Cognateness}_{ij} + (\beta_5 + u_{5_i} + w_{3_j}) \cdot (\text{Age}_i \times \text{Exposure}_{ij}) +\\
&(\beta_6 + u_{6_i}) \cdot (\text{Age}_i \times \text{Cognateness}_{ij}) +\\
&(\beta_7 + u_{7_i}) \cdot (\text{Exposure}_{ij} \times \text{Cognateness}_{ij})\\
&(\beta_8 + u_{8_i}) \cdot (\text{Age}_i \times \text{Exposure}_{ij} \times \text{Cognateness}_{ij})\\
&\text{where:}\\
&\beta_{1-8}\text{: fixed effects}\\
&u_{1-8_i}\text{: participant-level random effects}\\
&w_{1-3_j}\text{: TE-level random effects}\\
&\textbf{Prior}\\
\beta_{0_k} &\sim \mathcal{N}(-0.25, 0.5);\ \beta_{1-5} \sim \mathcal{N}(0,1)\\
\sigma_{u_{0-8}, w_{0-3}} &\sim \mathcal{N}_{+}(1, 0.25);\ \rho_{u_{0-8}, w_{0-3}} \sim \text{LKJcorr}(2)\\
&\text{where:}\\
&\sigma_{u_{0-8}, w_{0-3}}\text{: are the standard deviations of } u \text{ and } w\\
&\rho_{u_{0-8}, w_{0-3}} \text{ are the correlations between random effects in } u \text{ and } w
\end{aligned}
\tag{2.1}
$$

2.2.3.3 Model predictors

We developed the Exposure predictor to account for the fact that bilinguals' exposure to a given word-form is not only a function of the word-form's lexical frequency, but also of the quantitative input they receive from the language such word-form belongs to. We expressed lexical frequencies as the product between both variables. First, we extracted the child-directed lexical frequency of each word-form from the CHILDES database (MacWhinney, 2000; Sanchez et al., 2019). Using the corresponding lexical frequencies directly from Catalan and Spanish was not possible due to the low number of Catalan participants and tokens available in their corresponding CHILDES corpora, so they were extracted from the English corpora instead. We mapped the lexical frequencies of the English words to their Catalan and Spanish translations (see Fourtassi et al., 2020 for a similar approach), and transformed them to Zipf scores (Van Heuven et al., 2014; Zipf, 1945). We multiplied the resulting lexical frequencies by the reported degree of exposure of the child to Catalan or Spanish. For instance, for a child whose degree of exposure is 80% for Catalan and 20% for Spanish, the expected *Exposure* score to the Catalan word-form *cotxe* [car]—with a lexical frequency of 6.33—would be 5.06, while that of its translation to Spanish *coche* would be 1.27.

Following Floccia et al., we defined *Cognateness* as the phonological similarity between each word-form and its translation (see Equation 2.2). For each translation equivalent, we used the `stringdist` (van der Loo, 2014) R package to calculate the Levenshtein distance between the Catalan and the Spanish phonological transcriptions of the word-forms. The Levenshtein distance measures the number of editions (insertions, deletions, or substitutions) that one string of characters must go through to become identical to the other (Levenshtein, 1966). We divided the Levenshtein distance of each translation equivalent by the length of the longest word-form to correct for word-form length (longer strings are likely to show a larger number of mismatches). Finally, we subtracted the result from one so that it could be interpreted in terms of phonological similarity, instead of phonological distance. This led to a distance metric that ranged from zero to one, where zero indicates that both word-forms are completely different (e.g., /ˈtaw.lɐ/–/ˈme.sa/, table), and one indicates that the two word-forms are identical (e.g., /ˈmar/–/ˈmar/, sea) (Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al., 2018; Fourtassi et al., 2020; Heeringa & Gooskens, 2003; Schepens et al., 2012). Predictors were standardised before entering the model by subtracting the mean of the predictor from each value and dividing the result by the standard deviation of the predictor.

Measuring cognateness with the Levenshtein similarity (lev)

$$\text{Cognateness}(x, y) = 1 - \frac{\text{lev}(x, y)}{\max\{i, j\}}$$

$$\text{lev}(x, y) = \begin{cases} \max(i, j), \text{ if } \min(i, j) = 0 \\ \min \begin{cases} \text{lev}_{x,y}(i-1, j) + 1 \\ \text{lev}_{x,y}(i, j-1) + 1 \\ \text{lev}_{x,y}(i-1, j-1) + 1_{x_i \neq y_j} \end{cases} & \text{, otherwise} \end{cases}$$

where:

x, y : phonological transcriptions of the two word-forms

i, j : word length (i.e., number of phonemes) of x and y

(2.2)

2.2.3.4 Statistical inference

We assessed the practical relevance of the estimated regression coefficients of the model following J. K. Kruschke & Liddell (2018). First, we specified a region of practical equivalence (ROPE) from -0.025 to +0.025, in the probability scale. This region indicates the range of values that we considered equivalent to zero. We then summarised the posterior distribution of each regression coefficient with the 95% highest density interval (HDI). This interval contains the true value of this coefficient with 95% probability, given the data. Finally, we calculated the proportion of posterior samples in the 95% HDI that fell into the ROPE, noted as $p(\text{ROPE})$, which indicates the probability that the true value of the regression coefficient falls into the ROPE (and therefore should be considered equivalent to zero). For example, $p(\text{ROPE}) = .80$ indicates that, given our data, there is a 80% probability that the true value of the coefficient falls within the ROPE, and can therefore be considered equivalent to zero. See Section 2.5 for considerations about statistical power and sample size.

2.3 Results

The model posterior showed adequate chain convergence diagnostics and posterior predictive checks (see Section 2.5). Table 2.3 shows the summary of the posterior distribution of the fixed regression coefficients, and their degree of overlap with the ROPE. For interpretability, we report the estimated regression coefficients transformed to the probability scale[1]. The resulting values correspond to the maximum difference in probability of acquisition (*Comprehension* or *Comprehension and Production*) that

[1]The logit and probability scales relate non-linearly. This means that one logit difference is not necessarily translated to a unique value in the probability scale. For example, the probability of acquisition of a given word might increase in 5% when age increases from 22 to 23 months, the probability of acquisition of the same word might only increase in 0.2% when age increases from 31 to 32 months. The linear growth of the probability of acquisition differs along the logistic curve, and therefore deciding the age point at which to report the estimates of the regression coefficients in the probability scale is not trivial. Following Gelman et al. (2020), we report the maximum value of such coefficient, which corresponds to the linear growth (i.e., derivative) of the logistic curve at the age at which most participants were acquiring a given word. This value can be approximated by dividing the coefficient in the logit scale by four: $\hat{\beta}_j/4$, where $\hat{\beta}_j$ is the estimated mean of the posterior distribution of coefficient j.

corresponds to a one standard deviation change in each predictor.

We now present our analysis, and report a summary of the regression coefficients of interest. Table 2.3 shows the summary of the posterior distribution of the fixed regression coefficients, and their degree of overlap with the ROPE. For interpretability, we report the estimated regression coefficients transformed to the probability scale. The resulting values correspond to the maximum difference in probability of acquisition (Comprehension or Comprehension and Production) equivalent to a one standard deviation change in each predictor.

Table 2.3: Summary of the posterior distribution of fixed regression coefficients. β: median of the posterior distribution in the probability scale. 95% HDI: 95% highest density interval of the distribution. $p(\text{ROPE})$: overlap between the 95% HDI and the ROPE, indicating the posterior probability that the true value of the coefficient is equivalent to zero.

	β	95% HDI	$p(\text{ROPE})$
Intercepts (at 22 months)			
Comprehension and Production	0.434	[0.378, 0.489]	-
Comprehension	0.935	[0.92, 0.948]	-
Slopes (upper bound)			
Length (+1 SD, 1.56 phonemes)	-0.062	[-0.087, -0.036]	.000
Age (+1 SD, 4.87 months)	0.405	[0.357, 0.451]	.000
Exposure (+1 SD, 1.81)	0.234	[0.198, 0.264]	.000
Cognateness (+1 SD, 0.26)	0.058	[0.016, 0.103]	.102
Exposure $\times$ Cognateness	-0.057	[-0.068, -0.045]	.000
Age $\times$ Exposure	0.073	[0.039, 0.106]	.000
Age $\times$ Cognateness	0.014	[0.001, 0.027]	.928
Age $\times$ Exposure $\times$ Cognateness	-0.018	[-0.026, -0.01]	.908

The coefficient of *Age* showed the strongest association with the probability of acquisition (β = 0.405, 95% HDI = [0.357, 0.451]), with all posterior samples falling out of the ROPE. A one-month increment in age increased a maximum of 0.08 the probability of acquisition. Similarly, the word-form exposure index (*Exposure*) had a strong effect on the probability of acquisition (β = 0.234, 95% HDI = [0.198, 0.264]). All of the posterior samples of this regression coefficient excluded the ROPE. The impact of this predictor on the probability of acquisition was positive: for every standard deviation increase in exposure, the participant was 0.129 probability points more likely to acquire it. Word-form length also showed a significant association with probability of acquisition (β = -0.062, 95% HDI = [-0.087, -0.036]). For every phoneme in the word-form, participants were -0.04 probability points less likely to know it. The 95% HDI of the regression coefficient of the *Age* $\times$ *Exposure* interaction also excluded the ROPE (β = 0.073, 95% HDI = [0.039, 0.106]), showing that the effect of the word-form exposure index differed across ages: older children were more likely to acquire words with a higher exposure rate than younger children were.

Around 10.20% of the posterior samples of the main effect of *Cognateness* overlapped with the ROPE (β = 0.058, 95% HDI = [0.016, 0.103]). For every 10% increment in cognateness, the probability of word acquisition increased in 0.006. The effect of Cognateness interacted with that of *Exposure*: the 95% HDI of the regression coefficient of interaction excluded the

ROPE entirely (β = -0.057, 95% HDI = [-0.068, -0.045]), suggesting that the effect of *Cognateness* on a word's probability of acquisition changed depending on participants' exposure to the word-form. When *Exposure* was low (e.g., -1 *SD*), *Cognateness* increased the probability of acquisition substantially, while this effect was negligible for words with median or high exposure (+1 *SD*) (see Figure 2.1).

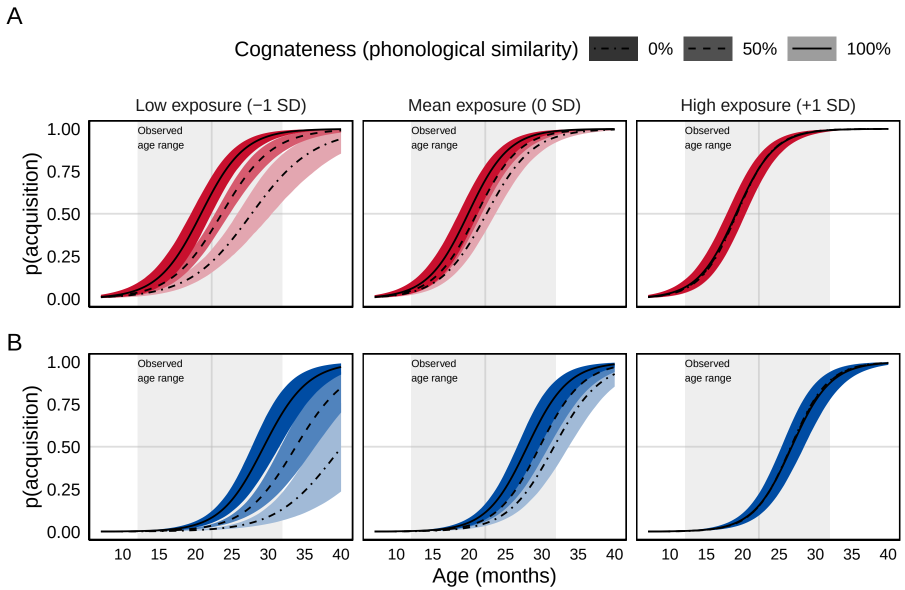

Figure 2.1: Posterior marginal effects for *Comprehension* (A) and *Production* (B). Lines and error bands correspond to the mean and 95% credible interval of the posterior-predicted means. Different colour shades indicate different levels of cognateness (phonological similarity). Predictions are presented separately for different degrees of the word-form exposure index: little exposure to the word-form, mean exposure, and high exposure. In-sample predictions lie inside the grey rectangles. For reference, we indicate the 50% chance level of word acquisition (horizontal grey lines), and the mean age of the sample (grey lines).

An additional analysis including lexical frequency and language exposure as separate predictors (instead of the composite Exposure measure) showed equivalent results (see Section 2.6). To rule out the possibility that cognateness facilitation effect we found was due to cognateness comprising more frequent syllables than non-cognates—and therefore not because of their cognate status itself—, we compared the syllabic frequency of cognates and non-cognates included in our analyses. To calculate syllable frequency, we first extracted all syllables embedded in the selected words. For each syllable, we summed the lexical frequency of all the words in which such syllable appeared. The resulting value provided an estimate of the number of times the syllable appears in child-directed speech, embedded within different words. Finally, for each word-form, we summed the frequency of its syllables, as an estimate of the syllabic frequency of the word-form. We fit a Bayesian model with Cognateness as response variable, and the main effects of syllable frequency and number of syllables (to control for the fact words with more syllables are more likely to score higher in syllabic frequency) as predictors. This model provided strong evidence for the association between cognateness and syllabic frequency being equivalent to zero (see Section 2.7).

2.4 Discussion

This study investigated the impact of cognateness (i.e., phonological similarity between translation equivalents) on the early bilingual lexicon. We used Bayesian item response theory to model the acquisition trajectories of a large sample of Catalan and Spanish words, estimating the effect of cognateness on the probability of acquisition. This model corrected for participants' age, word-form length (number of phonemes), and a novel measure of participants' exposure rate to each word-form. Exposure rates were calculated as a language exposure-weighted lexical frequency score in which each word-form's lexical frequency was corrected by the degree to which the participant was exposed to each language. Overall, we found that cognates (i.e., phonologically similar translation equivalents) were acquired earlier than non-cognates. This effect was mediated by exposure rate. Low-exposure word-forms benefited from their cognate status, whereas high-exposure word-forms did not. Using the concept of accumulator (see Kachergis et al., 2022 for review), we provide a theoretical account of bilingual lexical acquisition. In the present account, parallel activation of the two languages plays a central role during the acquisition of early representations in the bilingual lexicon, and in which the dynamics of co-activation between translation equivalents results in an earlier age-of-acquisition.

The present investigation is particularly relevant in the light of two previous findings. First, Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) reported that bilingual toddlers learning two typologically close languages (e.g., shared many cognates, like English-Dutch) showed larger vocabulary sizes than those learning typologically distant languages (e.g., shared fewer cognates, like English-Mandarin). Second, Mitchell et al. (2022) found an earlier age-of-acquisition for cognates, compared to non-cognates. The outcomes of both studies pointed to cognateness facilitating word acquisition through parallel activation, but the underpinnings of such effect were unclear. While parallel activation has been extensively described in experimental studies, current paradigms of bilingual word acquisition and word learning are, to a large extent, dissociated from the mechanisms proposed by previous work on word processing. The notion of accumulator, as conceptualised by accumulator models of language acquisition, may provide a convenient theoretical framework to narrow this gap.

Accumulator models devise word acquisition as a continuous process in which the child gathers information about words by accumulating learning instances with such words. When the number of cumulative learning instances for a word reaches some theoretical threshold, the child is considered to have acquired such word. The rate at which a child accumulates learning instances with a word is a function of child-level properties (e.g., ability, amount of quantitative language exposure) and word-level properties (e.g., lexical frequency) (Hidaka, 2013). Through statistical inference, formalised accumulator models provide meaningful information about parameters of interest like the aforementioned predictors (Kachergis et al., 2022; Mollica & Piantadosi, 2017), and allow to generate quantitative predictions about age-of-acquisition and vocabulary growth under competing theoretical accounts (Hidaka, 2013; McMurray, 2007). Using the notion of accumulator, we extended this type of account to the bilingual case. We suggested that the cognate facilitation effect on bilingual word acquisition is the result of cognate words being activated more strongly by their translation than non-cognates. This would lead cognate words to accumulate learning instances at a faster rate than non-cognate words. When a bilingual child is exposed to a word-form, they activate not only its corresponding lexical representation, but also the lexical representation of its translation. The amount of co-activation that spreads from the spoken word-form to its translation is proportional to the amount of phonological similarity between both word-forms. Cognates would receive more activation from their translation than non-cognates, leading children to accumulate learning instances with cognate words at a faster rate than with non-cognate words. As a result, lexical representations of cognate words would consolidate at earlier ages than those of non-cognate words.

These predictions address a critical subject in bilingualism research. Do bilingual infants accumulate learning experiences in both languages independently, or does exposure to one language impact the acquisition trajectory of the other language? In the context of lexical acquisition, the former scenario predicts that every learning instance for a given word-form contributes to the acquisition of the representation of such word in the lexicon, while the acquisition of its translation remains unaffected by such experience. In the latter scenario, a learning instance to the same word-form would contribute not only to the acquisition of the representation of the word, but also, to some extent, to the acquisition of its translation. Our findings provide strong support for an account of bilingual vocabulary growth in which the experience and learning outcomes accumulated by the child in one language impact those in the other language through cross-language phonological associations. Such a facilitatory mechanism might be an important piece in the puzzle of bilingual language acquisition. In particular, it may shed some light on why bilingual infants do not show relevant delays in language acquisition milestones compared to their mono-lingual peers, while receiving a reduced quantity of speech input in each of their languages. Infants in the present study benefited more strongly from the cognateness facilitation effect when acquiring words from the language of lower exposure than in the language of higher exposure.

This mechanism might be extended to provide a plausible explanation for the language similarity facilitation reported by Floccia et al. The authors observed a facilitation in the additional (non-English) language. Children learning two typologically close languages knew more words in the additional language than those learning two typologically more distant languages. In their sample, the additional language was consistently also the lower-exposure language for most children, while English was the higher-exposure language. Given that words in English were more likely to be acquired first, higher phonological overlap for words in the language of lower exposure (especially those of lower lexical frequency) would facilitate vocabulary growth for languages sharing more cognates with English.

The asymmetric facilitation of cognateness on word acquisition reported in the present study parallels previous findings in toddlers and adults. For instance, unbalanced (or low-proficiency) bilinguals benefit from cross-language forward priming (dominant to non-dominant) during word processing (De Groot & Nas, 1991; Grainger, 1998; Shook & Marian, 2019; Singh, 2014; Von Holzen et al., 2019; but see Jardak & Byers-Heinlein, 2019). One the other hand, backward priming (non-dominant to dominant) seems less robust and more challenging to detect (e.g., Hoshino et al., 2010; Midgley et al., 2009; but see Duyck & Warlop, 2009). Balanced (or high-proficiency bilinguals) show an equivalent priming facilitation in both directions (Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2009). These results have been taken as evidence for an asymmetry in the strength of forward and backward connections in the unbalanced bilingual lexicon. Although implemented in different ways, or found under different assumptions, such a dominance-mediated asymmetry is accounted for by multiple models of lexical processing like the Revised Hierarchical

Model (Kroll & Stewart, 1994), BIA/BIA+ (Dijkstra & Van Heuven, 2013), BLINCS (Shook & Marian, 2013), or Multilink (Dijkstra et al., 2019), and also by models providing a more development-oriented perspective, like the Ontogenic Model (Bordag et al., 2022; Cook et al., 2016), and BIA-d (Grainger et al., 2010). Overall, this provides an apparently convenient account for the interaction between language dominance and cognateness found in the present study. These models are aimed at explaining results in adults, and their predictions should be taken with caution when extended to early language acquisition.

In adult bilingual populations, language dominance and proficiency are frequently defined using dimensions other than degree of exposure, which is a more common practice in infant research (Marian & Hayakawa, 2021; Rocha-Hidalgo & Barr, 2023). For instance, low-proficiency bilinguals in many of the aforementioned studies acquired their second language years after their toddlerhood. We identify three critical ways in which this prevents a clear comparison between our results and those from studies on second language acquisition in adults. First, in adult second language acquisition, the acquisition of the phonology of the new language must be negotiated with the already acquired phoneme inventory of the first language (e.g., Cutler et al., 2006; Sebastian-Gallés et al., 2006), in place around the first year of life (see Werker & Hensch, 2015 for review). Second, adults acquiring a second language already possess a system of form-meaning mappings, whereas simultaneous bilingual infants must build a lexicon for two languages in the absence of clear form-meaning mappings. Third, adults are assumed to be literate and to possess an orthographic system in place, which may shape how new words are integrated in the lexicon and processed during experimental tasks (e.g., Thierry & Wu, 2007). In this scenario, the acquisition of a second language may take place in a substantially different way compared to how bilingual infants acquire two languages from birth. A more similar case to the one concerning the present study is considered by the DevLex-II model (Zhao & Li, 2010), which captures unique features of the early bilingual lexicon, and considers the case of infants simultaneously acquiring their two language. In line with the adult models, DevLex-II predicts asymmetries between word representation from the dominant and the non-dominant language. Simulations from DevLex-II result in an asymmetric cross-language priming, in which words from the dominant (acquired acquired) language primed more strongly the recognition of words in the non-dominant language (later acquired) than in the other direction (Zhao & Li, 2013).

In summary, there is a compelling case for attributing asymmetric effects of parallel activation to differences in activation strength between forward and backward connections. It is nonetheless possible that, as argued in the introduction, the asymmetric effect of cognateness found in the present study is simply the result of infants being exposed more frequently to words in the dominant language than to words in the non-dominant language. This would lead to words in the non-dominant language receiving additional parallel activation, compared to words in the dominant language, and therefore benefiting more strongly from their cognate status. These two accounts are not mutually exclusive, as words in the dominant language may active more strongly their translations than vice versa, on top of such activation being more frequent. Further research is needed in order to clarify this issue.

It might be argued that our results reflect the fact that cognate translation equivalents are represented in the initial bilingual lexicon as the same lexical entry. Because cognates correspond to similar sounding word-forms in equivalent referential contexts (e.g., hearing /ˈgat/ and /ˈga.to/ in the same situations), it is possible that infants classify both are as acceptable variations of the same word-form, therefore treating them as a single lexical item. This would lead to a faster increase in cumulative learning instances, and to an earlier age-of-acquisition for cognate translation equivalents (for which listening to each word-form contributes to the acquisition of its shared representation), compared to non-cognates (for which listening to each word-form contributes to the acquisition of a separate representation). This mechanism could potentially explain the earlier age-of-acquisition effect of cognates found in the present study, without the need of parallel activation playing any relevant role. Mitchell et al. (2022) discuss this possibility as a candidate explanation of the cognate facilitation effect, in which bilinguals only need to map one word-form to the referent in the case of cognates, while mapping two distinct word-forms in the case of non-cognates. However, previous work on mispronunciation perception and learning of minimal pair words points in a different direction. Bilingual toddlers show monolingual-level sensitivity to slight phonetic changes in a word-form, according to their performance in word recognition tasks (Bailey & Plunkett, 2002; Mani & Plunkett, 2011b; Ramon-Casas et al., 2009, 2017; Ramon-Casas & Bosch, 2010; Swingley, 2005; Swingley & Aslin, 2000; Tamási et al., 2017; Wewalaarachchi et al., 2017). The ability to differentiate between similar-sounding word-forms is also reflected in word learning, as bilinguals seem to be able to map minimal pairs to distinct referents (Havy et al., 2016; Mattock et al., 2010; Ramon-Casas et al., 2017). Overall, it seems that bilinguals consider small differences in the phonological forms of words as relevant at the lexical level. We argue that this shows evidence that bilingual toddlers likely form distinct lexical representations for even near-identical cognates.

Our study shares similar methodological limitations with previous work using vocabulary reports provided by caregivers. Such reports can be subject to measurement error induced by caregivers who may sometimes overestimate or underestimate participants' true probability of word acquisition (e.g., Houston-Price et al., 2007). In the case of bilingual research additional biases may be in place. Although in the present study caregivers were explicitly instructed not to rely on their responses to Catalan words when responding to Spanish (and vice versa), it is possible that some caregivers assumed—at least to some extent—that because the child knew a word in one language, the child should also know the word in the other language. This bias would especially affect similar-sounding words, i.e., cognates. Production estimates may be more prompt to such biases, in part because of the slower pace at which infants' articulatory abilities develop, compared to their word recognition abilities (Hustad et al., 2021). This gap between comprehension and production is even larger in the less dominant language of bilingual children (Giguere & Hoff, 2022). For this reason, caregivers may be more uncertain about what words can be counted as acquired in this modality. Despite such potential biases, vocabulary checklist filled by parents show strong evidence of concurrent validity with other estimates of vocabulary size or lexical processing (Feldman et al., 2005; Gillen et al., 2021; but see Houston-Price et al., 2007).

The present study contributes with a specific data point to the complex landscape of bilingualism research. Bilinguals are a remarkably heterogeneous population difficult to be satisfactorily characterised in a comprehensive way (Sebastian-Galles & Santolin, 2020). Bilinguals differ across multiple dimensions. Such differences span from exclusively linguistic factors; such as the amount of overlap between the phonemic inventories of the two languages being learned (e.g., low, like the case of English and Mandarin, or high, like the case of Spanish and Greek), to extralinguistic factors like the sociolinguistic situation in which the two languages co-exist (e.g., in some regions both languages are co-official and used in similar contexts, while in others, one of the languages has a smaller societal presence, i.e., heritage languages). This diversity of situations in which bilingual toddlers acquire language calls for special consideration of the generalisability of results in bilingualism research. Our sample, although homogeneous (e.g., similar parental educational level across participants), represents a particular bilingual sociolinguistic environment. The languages involved in the present investigation, Catalan and Spanish, co-exist in Catalonia as official languages, both languages are used in fairly similar contexts, and both languages are known by the majority of the population. In 2018, more than 81.2% of a representative sample of 8,780 adults aged 15 years or older living in Catalonia reported being able to speak Catalan, and more than 99.5% of the same population reported being able to speak Spanish (*Els Usos Lingüístics de La Població de Catalunya*, 2018). In addition, Catalan and Spanish are Romance languages and share a considerable amount of cognates. Extending our analyses to other bilingual populations learning typologically more distant languages, and whose languages tend to be used in more distinct contexts (e.g., heritage languages) should be a natural future step for the present investigation.

To conclude, our study provides novel insights about word acquisition in bilingual contexts, and how the presence of cognates in the children's linguistic input impacts the early formation of the lexicon. We found that during the acquisition of low frequency words, bilingual children seem to benefit more strongly from the word-form's phonological similarity with its translation in the other language. Capitalising on the notion of accumulator of linguistic input, we put forward a theoretical account of bilingual word learning, in which cognateness interacts with lexical frequency and language exposure to boost the acquisition of translation equivalents.

2.5 Appendix A: Model details

Model structure and prior. We used Stan (Carpenter et al., 2017) as the probabilistic language behind the estimation of our Bayesian models in this study, with `brms` as its R interface (Bürkner, 2017). This language implements the Markov Chain Monte Carlo (MCMC) algorithm using the Hamiltonian Monte Carlo method (HMC) to explore the posterior distribution of the model. Broadly, this algorithm is used to iteratively sample the joint sampling space of the parameters to be estimated in the model, and compute, for each value sampled, its likelihood under some probability distribution previously defined. We run four MCMC chains, each 1,000 iterations long each.

Considerations on statistical power and sample size. There is little consensus about what approach is adequate for calculating the statistical power of a complex Bayesian model like the one in the present study, for several reasons. A first pitfall, shared with frequentist analysis, is that a closed solution for statistical power calculation is not possible or cannot be computed within reasonable time constraints. This rules out the use of many available pieces of software that are commonly offered for power analysis, as they commonly only consider the case of simpler models like t-tests, ANOVA, Pearson correlation, or regression (with only fixed effects), or trivial derivations of thereof. The more complicated case of multilevel models is usually not covered, not to mention those with a Bayesian approach.

An alternative way of estimating the statistical power of statistical test is simulation. This consists on simulating multiple datasets in which the hypothesised effect size is present, and fitting multiple instances of the model. The statistical power is derived from the proportion of contrasts that result in the rejection of the null hypothesis across datasets. Although this approach permits the estimation of statistical power in the case of more complex models, it involves costly computations. In the case of Bayesian models, and particularly the one in the present study, such cost can be infeasible. Sampling the posterior of our model took approximately seven days. Running this model, or an equivalent one, across 100 datasets (100 may even be considered too few by many) would take more than a year.

Following J. Kruschke (2014), we considered the precision of our estimates as a proxy to statistical power. In particular, we compared the width of the 95% HDI of the critical regression coefficient (*Exposure* $\times$ *Cognateness*) against some nominal interval width. We decided to use the half the width of the ROPE in the logit scale [-0.025, +0.025], that is, 0.05 as the reference interval width. The width of the fixed regression coefficient of *Exposure* $\times$ *Cognateness* (β = -0.014, 95% HDI = [-0.017, -0.011]) was 0.006, around 8.933 times narrower than the reference interval. This indicates that the precision of the posterior 95% HDI of the critical parameter in the model is larger than required.

Model diagnostics. One way to diagnose the behaviour of the HMC algorithm is to inspect whether the different MCMC chains (if more than one) have converged to a similar region of the posterior. The Gelman-Rubin diagnostic ($\hat{R}$ or R-hat Gelman & Rubin, 1992) provides a measure of chain convergence by comparing the variance within each chain *versus* the variance between each chain. Both are expected to be identical when chains have perfectly converged, so that $\hat{R} = 1$. Values lower than 1.01 are recommended, while values higher than 1.05 indicate that chains might have trouble converging and therefore the estimated parameters must be taken with caution. Figure 2.2 (A) shows the distribution of $\hat{R}$ values for the coefficients of the fixed effect of our models, which we used for statistical inference. Most values are lower than 1.01, and never higher than 1.05, which provides evidence of successful MCMC convergence.

Another diagnostic of good MCMC converge is the ratio of effective sample size to total sample size (N_{eff}/N), which indicates the proportion of samples in the chain that resulted from a non-divergent transition. Values closer to 1 are ideal, as they indicate that all posterior samples from the MCMC were used to estimate the posterior distribution of the parameter. Values larger than 0.1 are recommended. Figure 2.2 (B) shows the distribution of the effective sample sizes of the coefficients of the fixed effects in our models. Most values are larger than 0.1, although model 0 ($\mathcal{M}_0$) accumulates most effective sample sizes close to 0.1.

Another way of assessing the behaviour of the HMC algorithm is to visualise the joint posterior distribution for pairs of parameters using bi-variate scatter plots. In Figure 2.3 we show the pair-wise distribution of posterior samples. Broadly, posterior samples of two parameters should not be correlated. This is the case for all pairs of parameters but for the two intercepts. This is expected behaviour, given that these two parameters correspond to the thresholds between categories in the ordinal regression model, and the distance between both thresholds is fixed in the particular parametrisation of the model.

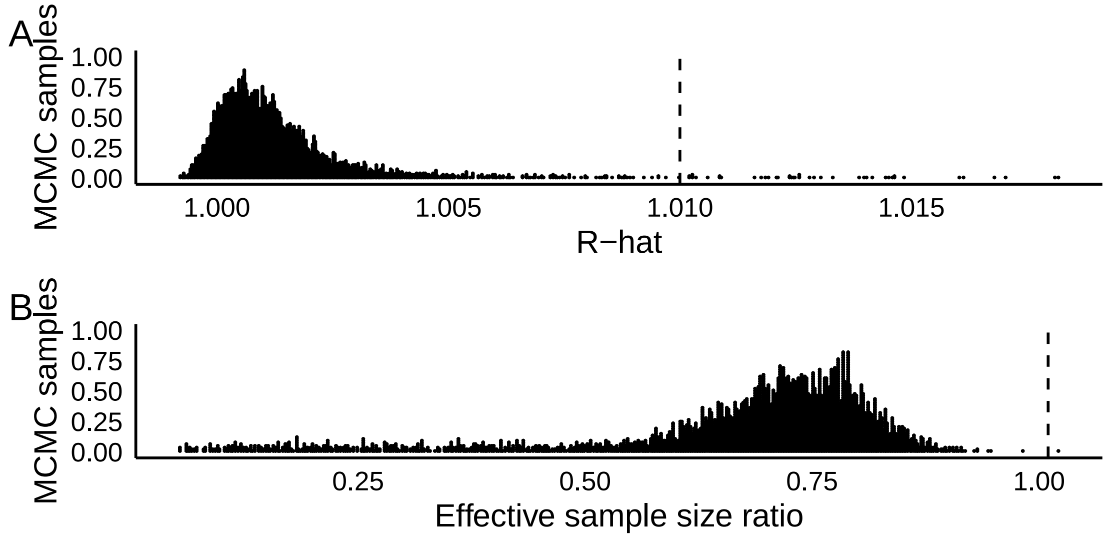

Figure 2.2: MCMC convergence diagnostic of all parameters in the model. Each dot represents the score of one parameter. (A) Distribution of the Gelman-Rubin (R-hat) scores. (B) Distribution of the ratio of effective sample size.

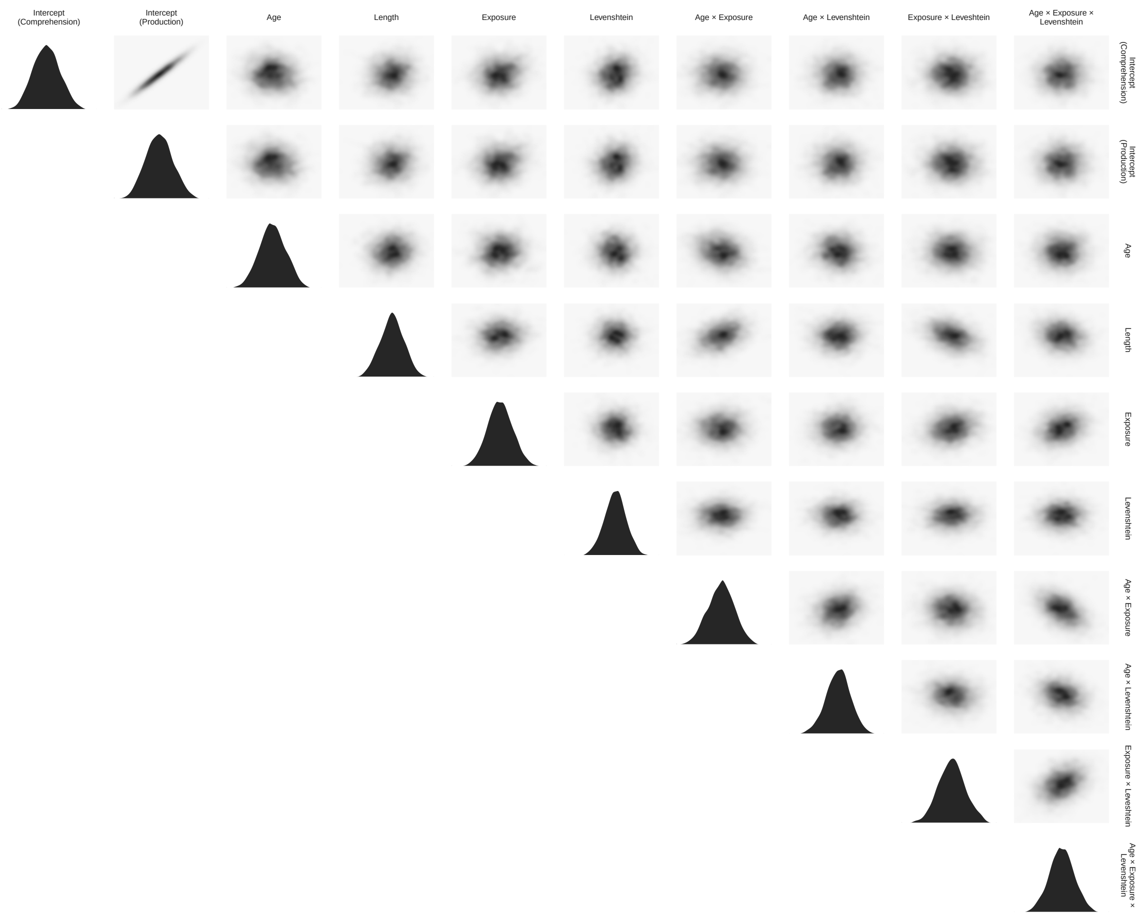

Figure 2.3: Marginal distribution and bi-variate scatterplot of posterior samples for the fixed regression coefficients in the model.

2.6 Appendix B: Frequency and language exposure as separate predictors

As a robustness check, we fit a model similar to the one described in the main manuscript, but including lexical frequency and language degree of exposure as separate predictors, instead of the composite measure *Exposure*. Language degree of exposure (*DoE*) was included in interaction with *Age* and *Cognateness*, while lexical frequency (*Frequency*) was included as a main effect. Table 2.4 shows a comparison between the posterior distribution of the regression coefficients of both models. Overall, results are equivalent.

Table 2.4: Posterior distribution of regression coefficients of the model including the *Exposure* composite predictor, and of the model including lexical frequency (*Frequency*) and degree of exposure (*DoE*) separately. β: median of the posterior distribution in the probability scale. 95% HDI: 95% highest density interval of the distribution. p(ROPE): overlap between the 95% HDI and the ROPE, indicating the posterior probability that the true value of the coefficient is equivalent to zero.

	β	95% HDI	p(ROPE)
Model: Exposure			
Length (+1 SD, 1.56 phonemes)	0.485	[0.478, 0.491]	.000
Age (+1 SD, 4.87 months)	0.600	[0.588, 0.611]	.000
Exposure (+1 SD, 1.81)	0.558	[0.549, 0.566]	.000
Cognateness (+1 SD, 0.26)	0.514	[0.504, 0.526]	.102
Exposure × Cognateness	0.486	[0.483, 0.489]	.000
Age × Exposure	0.518	[0.51, 0.526]	.000
Age × Cognateness	0.504	[0.5, 0.507]	.928
Age × Exposure × Cognateness	0.495	[0.493, 0.497]	.908
Model: Frequency & DoE			
Age (+1 SD, 4.87, months)	0.600	[0.59, 0.612]	.000
Phonemes (+1 SD, 1.56 phonemes)	0.486	[0.48, 0.492]	.000
Frequency (+1 SD, 0.19)	0.527	[0.516, 0.539]	.000
DoE (+1 SD, 0.3)	0.557	[0.549, 0.566]	.000
Cognateness (+1 SD, 0.26)	0.516	[0.505, 0.527]	.064
Age × DoE	0.518	[0.51, 0.526]	.000
DoE × Cognateness	0.486	[0.483, 0.488]	.000
Age × Cognateness	0.504	[0.501, 0.507]	.852
Age × DoE × Cognateness	0.495	[0.493, 0.497]	.900

2.7 Appendix C: Syllable frequency

We define syllable frequency as the rate of appearance of individual syllables in the word-forms included in the Barcelona Vocabulary Questionnaire (BVQ) (Garcia-Castro et al., 2023). Each item corresponds to a Catalan or Spanish word, and has an associated phonological transcription in X-SAMPA format (Wells, 1995). These transcriptions are syllabified. Some examples:

Table 2.5: Sample of items included in the BVQ questionnaire and their syllabified SAMPA transcriptions in Catalan and Spanish.

Translation	Item	X-SAMPA	Syllables	Item	X-SAMPA	Syllables
white	blanc	b5aN	1	blanco	"blan.ko	2
ham	pernil	p@r"ni5	2	jamón (york)	"xa"mon	2
knee	genolls	Z@"noLs	2	rodillas	ro"Gi.Las	3
stairs	escalaes	@s"ka.5@s	3	escaleras	eska"le.4as	3
candy	caramel	k@.4@"mE5	3	caramelo	ka.4a"me.lo	4
orange (food)	taronja	"t4OJ.Z@	2	naranja	na"4an.xa	3
turtle	tortuga	tur"tu.G@	3	tortuga	to4"tu.Ga	3
strawberry	maduixa	m@"Du.S@	3	fresa	"f4e.sa	2
park	parc	park	1	parque	"pa4.ke	2
uncle	oncle	"oN.k5@	2	tío	"ti.o	2
cookie	galeta	g@"5E.t@	3	galleta	ga"Le.ta	3
zipper	cremallera	k4@.m@"Le.4@	4	cremallera	k4e.ma"Le.4a	4
syrup	xarop	S@"4Op	2	jarabe	xa"4a.Be	3
book	llibre	"Li.B4@	2	libro	"li.B4o	2
yard	jardí	Z@r"Di	2	jardín	xa4"Din	2

Most Catalan and Spanish words had two syllables, with Spanish words having three and four syllables more often than Catalan words. Less than 1% of the words included in the analyses presented in the main body of the manuscripts had five syllables. No words had more than five syllables (see Figure 2.4). We extracted lexical frequencies from the English corpora in the CHILDES database (MacWhinney, 2000; Sanchez et al., 2019). Using the Catalan and Spanish corpora was not possible due to the low number of children and tokens included in the corpora.

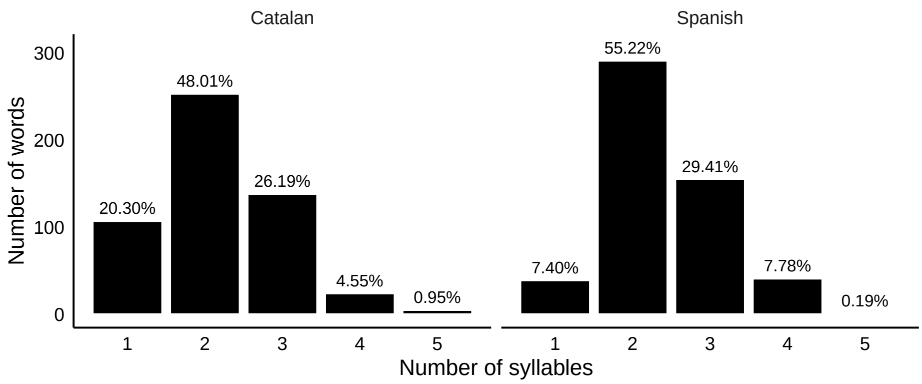

Figure 2.4: Distribution of the number of syllables in Catalan and Spanish

We now present how syllable frequencies were calculated. Every exposure to a word-form also counts as a exposure to each of the syllables that make up such word. Every time a child hears the word *casa* [house], they are exposed to the syllables *ca* and *sa*. Syllables that appear embedded in words with higher lexical frequency will also be more frequent. To compute the relative frequency of each syllable in Catalan and Spanish (i.e., how many times the syllables appears in every million words in Catalan or Spanish speech), we summed the relative lexical frequency in CHILDES of every word that contains such syllable in the corresponding language. Figure 2.5 shows the distribution of frequencies across syllables in Catalan and Spanish. In the log10 scale, syllable frequencies in Catalan and Spanish followed a slightly asymmetric distribution, with most syllables scoring around 1,000 counts per million, and a longer tail to the right of the distribution.

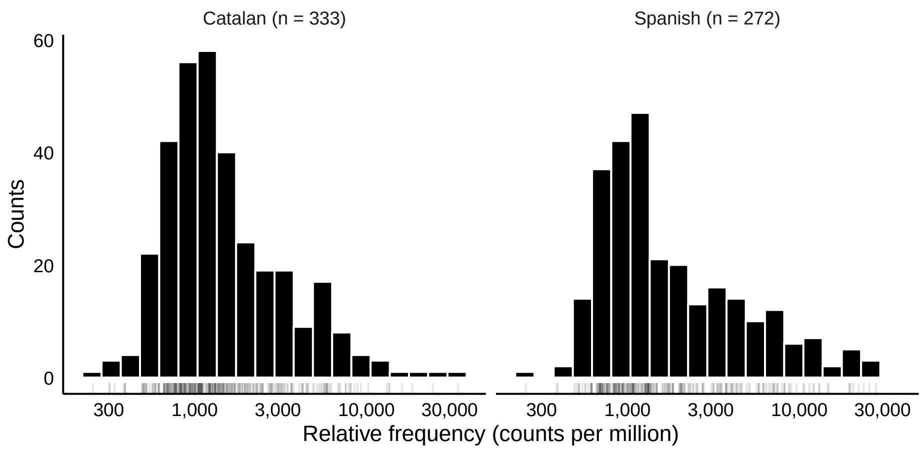

Figure 2.5: Distribution of apositional syllable frequencies in Spanish and Catalan

To estimate the association between word-level syllabic frequency and cognateness, while controlling for the number of syllables in the word, (an increment in the number of syllables necessarily increases the summed syllabic frequency of the word), we fit a multilevel, Bayesian linear regression model with syllabic frequency (the sum of the syllabic frequency of the syllables in a word) as response variable, and the main effect of the number of syllables (*Syllables*) and *Cognateness* (Levenshtein similarity between a word and its translation equivalent, Levenshtein, 1966) as predictors. We added translation equivalent-level random effects for the intercept and the main effect of *Syllables* (some translation pairs had a different number of syllables in each language). We used a Gaussian distribution to model syllabic frequency scores after standardising this variable and the predictors. We used a weakly informative prior for all parameters involved in the model. We conducted statistical inference by evaluating the proportion of the 95% highest density interval (HDI) of the posterior posterior distribution of each coefficient that fell into the region of practical equivalence (ROPE, see the main manuscript for a more detailed explanation, J. K. Kruschke & Liddell, 2018).

We fit this model running 4 sampling chains with 1,000 iterations each. Table 2.6 shows a summary of the posterior distribution of the fixed effects in the model. As expected, words with more syllables scored higher in syllabic frequency: all posterior draws for the regression coefficient of the main effect of this predictor fell outside the ROPE defined between -0.5 and +0.5 (β = 5.64, 95% HDI = [5.58, 5.71]). Keeping the number of syllables constant, the effect of cognateness was negligible: all of the posterior distributions of this predictor fell within the ROPE, providing evidence that the true value of the increment in syllabic frequency for every increase in cognateness is equivalent to zero (β = 0.01, 95% HDI =

Table 2.6: Posterior distribution of regression coefficients. β: median of the posterior distribution in the probability scale. 95% HDI: 95% highest density interval of the distribution. p(ROPE): overlap between the 95% HDI and the ROPE, indicating the posterior probability that the true value of the coefficient is equivalent to zero.

	β	95% HDI	p(ROPE)
Intercept	16.090	[16.022, 16.162]	NA
Syllables (+1 SD, 0.802)	5.644	[5.575, 5.713]	.000
Cognateness (+1 SD, 0.24)	0.009	[-0.056, 0.081]	1.000

[-0.06, 0.08]).

Figure 2.6 shows the median posterior-predicted syllabic frequencies for words with one to four syllables, for the whole range of cognateness values. Overall, cognate words' syllabic frequency is equivalent to that of non-cognates. This suggests that the cognate facilitation effect in word acquisition reported in the present study is not the result from an association between cognateness and higher syllabic frequencies.

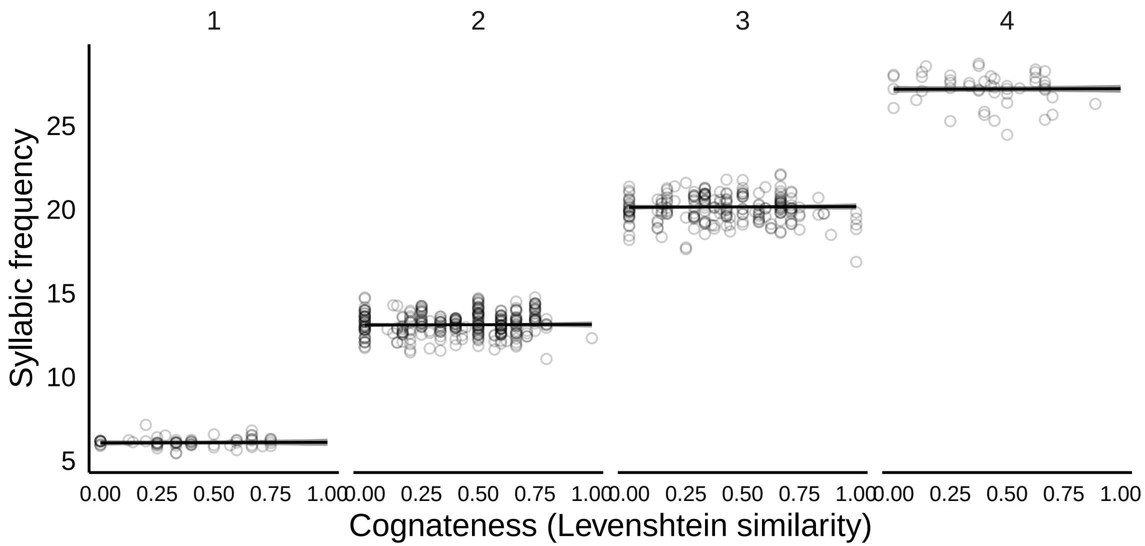

Figure 2.6: Posterior-predictions of the syllabic frequency model. Thicker lines indicate the median of the posterior predictions, and thinner lines indicate individual posterior predictions.

3 Chapter 3

3.1 Introduction

Building a mental lexicon is a major achievement in the development of an infant: by storing representations of how familiar words sound and what they mean, an infant is able to make sense of their linguistic input. The foundations of an initial lexicon are in place before the end the first year of life (Bergelson & Swingley, 2012, 2015; Hallé & de Boysson-Bardies, 1994; Parise & Csibra, 2012; Tincoff & Jusczyk, 1999; M. Vihman, 2004). This initial lexicon consists of only a few items; mainly words for people, interjections, body parts, and food (Tardif et al., 2008; Tincoff & Jusczyk, 2012), but it undergoes rapid growth during the second year of life (Bergelson, 2020; Bloom, 2002; Ganger & Brent, 2004; Goldfield & Reznick, 1990; McMurray, 2007). According to parental reports, the average 15-month-old infant already understands more than 100 words, and by two years of age, they understand more than 400 (Frank et al., 2021). This accelerated lexical developmental is reflected in infants' trajectories of word recognition: infants recognise familiar words faster and more efficiently as they approach their second birthday (Fernald et al., 1998, 2001; Hurtado et al., 2007). Despite being exposed to a more complex linguistic input, bilinguals show equivalent trajectories of word acquisition and word recognition to their monolingual peers' (Bialystok, 2009; Byers-Heinlein et al., 2023; De Houwer et al., 2014; Hoff et al., 2012; Legacy et al., 2018; Pearson & Fernández, 1994; M. Vihman et al., 2007). This is a remarkable deed for two reasons. First, bilingual infants receive a relatively reduced linguistic input in each of their languages, compared to monolinguals (Cattani et al., 2014; Costa & Sebastián-Gallés, 2014; Thordardottir, 2011). Second, they face a more complex referential context: they often learn two labels for each referent (one in each language), which additionally may not be direct translations of each other (Au & Glusman, 1990; Bilson et al., 2015; De Houwer et al., 2006; R. K.-Y. Tsui et al., 2022). The mechanisms that allow bilingual' trajectories of lexical developmental to keep up with monolinguals' are still unclear.

Previous studies have pointed to the similarity between the two languages of exposure as a facilitator of lexical acquisition in bilinguals (Blom et al., 2020; Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, & others, 2018; Gampe et al., 2021). Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, & others (2018) reported larger vocabulary sizes in bilingual toddlers leaning two languages that shared high lexical similarity. The authors collected parental reports of vocabulary data from a sample of 367 bilingual children living in the United Kingdom, who were learning English and an additional language (out of a diverse pool of 13 languages). The authors then calculated the average phono-lexical similarity between English and each of the additional languages. English and Dutch shared the highest similarity, while English and Mandarin shared the lowest. Overall, children's vocabulary sizes in the additional language was positively associated with the amount of language similarity between their two languages. For instance, English-Dutch bilinguals showed larger vocabulary sizes in Dutch than English-Mandarin bilinguals did in Mandarin. The authors suggested that the acquisition of words in the additional language might be facilitated by their cognate status (i.e., being phonologically similar to their translation equivalent). If this is the case, larger vocabulary sizes might then be expected in bilinguals learning two languages sharing a high proportion of cognates. This would be consistent with available evidence of an earlier acquisition of cognate words (Bosch & Ramon-Casas, 2014; Mitchell et al., 2022; Schelletter, 2002), and with the results in Chapter 2.

The facilitation effect of cognateness is in line with the language non-selective account of bilingual lexical access. This account proposes that bilinguals activate both languages in parallel, even during monolingual situations. In adults, there is robust evidence in favour of this language non-selective account of lexical access (de Groot, 1992; Dijkstra et al., 1999, 2010; Dufour & Kroll, 1995; Marian & Spivey, 1999; Schwartz et al., 2007; Spivey & Marian, 1999). Costa et al. (2000) presented highly-proficient Catalan-Spanish bilinguals with a series of pictures of familiar objects. Participants were asked to name each picture in Spanish. Unbeknownst to participants, the authors manipulated the cognate status pictures' labels in Catalan and Spanish. In half of the trials, the labels associated with the pictures were cognates (e.g., *cat-gat* [cat]), whereas in the other half of the trials the labels were non-cognates (e.g., *taula-mesa* [table]). Participants named pictures faster in cognate trials than in non-cognate trials. Spanish monolinguals showed equivalent naming times in both conditions. These results revealed that bilinguals activated their Catalan phonology, despite performing the naming task exclusively in Spanish: the visual recognition of the presented pictures led to the parallel activation of its associated phonological forms in both languages, which influenced the subsequent dynamics of word production.

Parallel activation has also been reported in the developing lexicon (Bosma et al., 2019; Bosma & Nota, 2020; Floccia et al., 2020; Jardak & Byers-Heinlein, 2019; Poarch & Van Hell, 2012; Singh, 2014; Von Holzen et al., 2019). Von Holzen & Mani (2012) found evidence of cross-language phonological priming in a sample of 20 German-English bilinguals aged 21 to 43 months. In their experimental task, each trial begun with the auditory presentation of an English prime word, followed by a target word in German, and a pair of target and distractor pictures. The authors recorded participants' target picture looking as a measure of target word recognition. The authors manipulated the cross-linguistic phonological overlap between the prime and the target labels. In a *priming through translation* condition, the English prime labels (leg) did not overlap with the German target labels (*Stein* [stone]), but with their German translations (*Bein*) did. In the *unrelated* condition, prime and target labels were not phonologically related in either German or English. If participants accessed their lexicon in a language non-selective way, the auditory presentation of the prime label in English should lead to the co-activation of its German translation. If this is the case, target word recognition should be interfered by the prior activation of a phonologically related German prime label. Under this hypothesis, the authors anticipated an delayed target looking in priming through translation trials, compared to unrelated trials. The results supported this hypothesis. In spite of the relevance of Von Holzen & Mani (2012) study, some methodological issues deserve some consideration. First, for most participants, exposure to English (the less prevalent language) was lower than the minimal amount conventionally considered the threshold for bilingual exposure (Byers-Heinlein et al., 2021; Rocha-Hidalgo & Barr, 2023). Second, some of the prime labels in the priming through translation condition were cognates. If both English and German labels overlap phonologically with the German target label, priming effects can be explained by interference between words from the same language, as opposed to cross-language interference. Third—and most critically—participants were exposed to both English and German word in a by-trial basis. This creates a context in which interference effects may not have arised from the competition between the prime translation and the target words, but between the target word and any other word in the other language. Paradigms in which the experimental task is conducted exclusively in one language, while cross-linguistic features are covertly manipulated, offer a methodologically stronger basis for studying language non-selectivity in the developing lexicon (Grosjean, 1997).

Mani & Plunkett (2010) designed an implicit naming task, in which primes consisted of pictures presented in silence, instead of auditory labels. In each trial, English monolingual infants were first presented with pictures of familiar objects for 1,500 ms. Then, a target-distractor picture pair was presented for 2,000 ms, and then the auditory label of the target picture was presented. Post-naming target looking was recorded for another 2,000 ms until the end of the trial, as a measure of target word recognition. The authors manipulated the phonological overlap between the prime and the target labels, so that in half of the trials both labels were phonologically related, sharing phonological onset (cat-cup), or phonologically unrelated (ball-comb). Prime, target and distractor were unrelated otherwise. At 18 months of age, participants showed a stronger looking preference for the target pictures after phonologically related prime pictures, compared to after phonologically unrelated primes. Since the prime pictures were presented in silence, their results suggested that infants implicitly named the prime pictures, and that the phonology of the resulting word interacted with the subsequent recognition of the auditory target word. Later, Mani & Plunkett (2011a) tested 21-month-old infants in the same task. This time, priming effects were observed in the opposite direction: when prime and target labels were phonologically related, participants showed significantly weaker target looking preference, compared to unrelated trials. The size of this interference effect was associated with participants' vocabulary size, and to the cohort size of the prime label. The authors interpreted this finding as indicating a developmental shift. At 18 months, participants' word recognition might have experienced a sub-lexical facilitation effect, in which the prior activation of the shared phonological onset between the prime and target labels boosted word recognition. In older participants, the lexicon might have reached a critical size at which the recognition of the target was delayed by the activation of its phonological cohort.

The implicit naming paradigm provides an ideal experimental paradigm to study the developing bilingual lexicon. By covertly manipulating the cross-linguistic relationship between the prime and target labels, parallel activation can be tested while participants are presented with auditory stimuli (target labels) exclusively in one of their languages (see Von Holzen & Mani, 2014 for a similar approach in bilingual adults). Capitalizing on the language non-selective account of lexical access, we exploited the implicit naming to investigate the mechanisms behind the emergence of phonological priming effects in the bilingual developing lexicon. We tested a cohort of monolingual and bilingual infants learning Catalan and Spanish between 20 and 32 months of age. We compared the performance of participants with differing vocabulary sizes in the word recognition task. In order to circumvent the problem of limited vocabulary knowledge in the non-dominant language, we tested participants only in their dominant language (Costa & Sebastián-Gallés, 2014).

Following Mani & Plunkett (2010), each trial in the task started with the silent presentation of a prime picture. Both monolingual and bilingual infants were expected to implicitly name the prime picture. According to the language non-selective hypothesis of lexical access, bilinguals should generate two labels for the prime picture, one in each language. To test this prediction, we manipulated the phonological similarity between the prime and the target words in both languages (see Figure 3.1). In *Related/Non-cognate* trials, prime and target labels shared phonological onset in only the language of test. For instance an infant tested in Catalan would be presented with a chair as prime picture (**c**adira$_{\text{CAT}}$/silla$_{\text{SPA}}$ [chair]) and with **c**ullera$_{\text{CAT}}$ [spoon] as target label. In line with Mani & Plunkett (2011a), we anticipated that the phonological overlap between prime and target should modulate target word recognition in both monolinguals and bilinguals. This should be reflected in a delayed target looking preference, compared to *Unrelated* trials, in which prime and target did not share phonological onset. In *Related/Cognate* trials, the prime shared phonological onset with the target in both languages. For instance, the same infants tested in Catalan would be presented with a car as prime picture (**c**otxe$_{CAT}$/**c**oche$_{SPA}$) and with **c**ullera$_{CAT}$ [spoon] as target label. In bilinguals, parallel activation of the prime in both languages should increase the cohort of the target word, leading to stronger interference effects in this condition, compared to *Related/Non-cognate* and *Unrelated* trials.

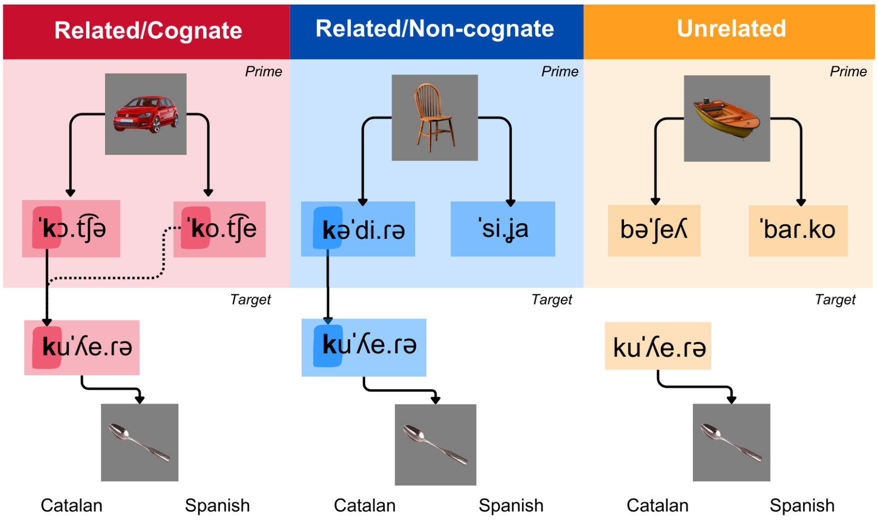

Figure 3.1: Predicted priming effects (or their absence) in the *Related/Cognate*, *Related/Non-cognate*, and *Unrelated* conditions, with examples for a participant tested in Catalan. Words represent lexical representations. Lexical representations of the task-relevant language (Catalan) are depicted inside grey boxes. Solid arrows indicate within-language priming effects, and dashed lines indicate cross-language priming effects. In *Related/Cognate* (A) and *Related/Non-cognate* (B) trials, the recognition of the Catalan target word ku'ʎe.rə [spoon] is predicted to be modulated by the prior activation of the prime label in Catalan. In *Related/Cognate* trials, the parallel activation of the prime label in Spanish is predicted to increase the strength of the priming effect.

In line with previous studies in monolinguals, we further predicted that the strength of the lexical interference effects in the *Related/Non-cognate* and *Related/Cognate* conditions would be associated with participants' vocabulary size. Target word recognition should be delayed by the activation of a larger cohort of phonologically related words (Avila-Varela et al., 2021; Chow et al., 2017; Mani & Plunkett, 2011a; Mayor & Plunkett, 2014). We defined vocabulary size as the amount of words participants were reported to understand in their dominant language by their caregivers. The choice of the dominant language for calculating vocabulary sizes is due to several reasons. First, it allows a more fair comparison between monolinguals (who do not know any language other than their dominant language) and bilinguals (who may know words in a second language). Second, since participants were tested exclusively in their dominant language, their vocabulary size in the dominant language is more likely to be associated with participants' performance in the task. Third, previous work on word recognition in bilinguals suggests that vocabulary size in the dominant language predicts participants' performance better than total vocabulary (in which vocabulary sizes in both languages are summed together) (Marchman et al., 2010).

Because of the short-lived effects of cross-language activation on lexical processing, and to maximise the probability of detecting priming effects, we introduced a change in the sequence of the trials relative to the original implementation by Mani & Plunkett (2010). We presented target auditory labels immediately after the offset of the prime picture, and before the onset of the target and distractor pictures. By presenting prime pictures and target auditory labels closer in time, implicit naming of the prime picture should be more likely to influence the recognition of the target word. To test the effects of this methodological change, we first run a control experiment, Study 1, in which we tested a group of same-aged English monolinguals. In Study 2, we tested a group of monolinguals and bilinguals learning Catalan and Spanish.

3.2 Study 1

In this study, we conducted a conceptual replication of Mani & Plunkett (2010) and Mani & Plunkett (2011a). We tested a group of English monolinguals aged 20 to 32 months, living in the Oxfordshire area (United Kingdom). As just said, participants were tested exclusively in English. As in the original studies, we manipulated the phonological relationship between the prime and the target label. We expected participants' target looking to change as a function of the phonological relatedness between the prime and target English labels. This would reveal that participants implicitly named the prime pictures, generating a phonological label that influenced the subsequent recognition of a phonologically related word. In half of the trials the English prime label was phonologically related to its Spanish translation, that it they were cognates; in the other half they were not phonologically related (non-cognates)[1]. Given participants' lack of knowledge of Spanish (or any language other than English), participants' performance was predicted to be unaffected by the cognate status of the primes.

In this study, we conducted a conceptual replication of Mani & Plunkett (2010) and Mani & Plunkett (2011a). We tested a group of English monolinguals aged 20 to 32 months, living in the Oxfordshire area (United Kingdom). As highlighted in the introduction, participants were tested exclusively in English, their dominant language. As in the original studies, we manipulated the phonological relationship between the prime and the target label. In line with Mani & Plunkett (2011a), we predicted participants' target looking to change as a function of the phonological relatedness between the prime and target English labels. This would reveal that participants implicitly named the prime pictures, generating a phonological label that influenced the subsequent recognition of a phonologically related word. To establish a monolingual baseline for all conditions in Study 2, we also manipulated the cognate status of the prime in English and Spanish: in half of the trials the English prime label was phonologically related to its Spanish translation. Given participants' lack of familiarity with

[1]It was initially planned to collected data from English monolinguals and English-Spanish bilinguals in Oxford, therefore the manipulation of the cognate status of the words in English and Spanish. Due to time limitations imposed by the COVD-19 lockdown between 2020 and 2022, collecting data from bilinguals was not possible. We report the available data from English monolinguals as a control for Catalan and Spanish monolinguals and bilinguals from Barcelona in Study 2.

Spanish (or any language other than English), participants' performance was predicted to be unaffected by the cognate status of the primes.

3.2.1 Methods

All materials, data, and reproducible code can be found at the OSF (https://osf.io/hy984/) and GitHub (https://github.com/gongcastro/cognate-priming) repositories. This study was conducted according to guidelines laid down in the Declaration of Helsinki, and was approved by the Drug Research Ethical Committee (CEIm) of the IMIM Parc de Salut Mar, reference 2020/9080/I and the Medical Sciences Research Ethics Board at the University of Oxford, reference R60939/RE009. Before every testing session, caregivers were asked to read and sign an informed consent form, and were given a token of appreciation at the end of it.

3.2.1.1 Participants

We collected data from 112 children (41 female, 68 male, with three additional participants' sex not being reported; Age: *Mean* = 26.36 months, *SD* = 4.01, *Range* = 20.03–32.5) (see Table 3.1 for a detailed summary of participants' age and language profile), living in the Oxfordshire area (United Kingdom). Participants were tested at the Oxford BabyLab at the University of Oxford. Families were recruited from maternity rooms in private hospitals and social media, and contacted via phone when the child's age spanned between 20 and 32 months. From the 112 children that participated, 97 participated once, and 15 participated twice. Recurrent participants were tested with at least 2.82 months of difference. We gathered a total of 127 testing sessions. All participants were being raised in exclusively British English monolingual homes. Participants' vision was normal, none used glasses or any other type of vision corrector.

Table 3.1: Demographic and linguistic profile of testing sessions in Study 1. The number of excluded testing sessions and participants is indicated between parentheses.

	Sample size		Age (months)	Degree of Exposure (%)		
				English	Catalan	Spanish
	Test sessions	Participants	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Study 1: Monolingual						
English dominant	89 (21)	79 (21)	26.5 (4.1)	100.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Study 2: Monolingual						
Catalan dominant	65 (7)	46 (6)	25.2 (3.8)	0.2 (0.8)	62.0 (10.3)	37.6 (10.5)
Spanish dominant	42 (7)	31 (7)	25.6 (3.4)	0.4 (1.6)	38.5 (10.4)	61.1 (11.0)
Study 2: Bilingual						
Catalan dominant	87 (8)	50 (7)	25.8 (3.9)	0.4 (2.2)	95.1 (6.2)	4.5 (6.0)
Spanish dominant	46 (7)	28 (6)	25.2 (3.8)	0.2 (0.8)	8.7 (6.4)	90.8 (6.4)

We collected vocabulary data using parental responses to the Oxford Communicative Development Inventory (OCDI) (Hamilton et al., 2000). The OCDI is an adaptation of the MacArthur-Bates Communicative Development Inventory (Fenson et al., 1994) to British English. The OCDI includes a vocabulary checklist containing 418 words from 21 semantic-functional categories (e.g., action words, animals, household objects, adverbs, etc.). For each word, caregivers are asked to answer if they child is able to *understand*, *understand and say* or does not understand or say the word. We calculated participants' receptive vocabulary size scores as the number of words that caregivers marked as *understands* or *understands and says*. Families were sent the questionnaire immediately after each experimental session, and were given two weeks to fill it. In the case that a complete response to the OCDI was not provided within the two-week limit, the participants' testing session was excluded from the analyses (n = 3). Figure 3.2 shows the distribution of participants' vocabulary sizes across ages.

3.2.1.2 Design

Participants were presented with 32 trials in random order, which belonged to two conditions: *Related* and *Unrelated* trials. In *Related* trials (n = 16), the English label of the prime was phonologically related to the target label, sharing phonological onset (e.g., /ˈtɹiː/$_{\text{ENG}}$[tree]–/ˈtɹʌk/$_{\text{ENG}}$[truck]).

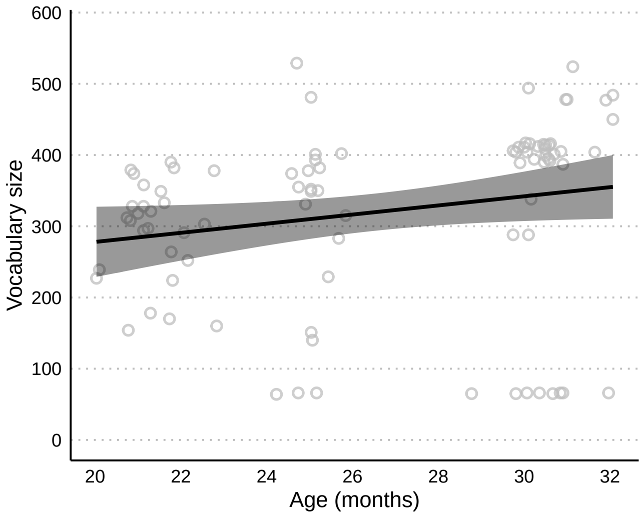

Figure 3.2: Participant receptive vocabulary sizes across ages and language profiles. For descritive purposes, mean and standard error of the mean are indicated, as calculated using a linear regression model.

In *Unrelated* trials, the prime and target labels did not share phonological onset (e.g., /ˈdɔː/$_{\text{ENG}}$[door]–/ˈsɒk/$_{\text{ENG}}$[sock]). Especial attention was paid to avoiding semantic or taxonomic relationships between prime and target words, and between prime and distractor words. Distractors were always phonologically unrelated to the prime and target labels in the same trial.

Figure 3.3 illustrates the sequence of a trial. Each trial started with the presentation of an attention getter for 3,000 ms. Then, the prime picture was presented in silence in the centre of the screen for 1,500 milliseconds. Fifty milliseconds after the offset of the prime image, an auditory label was played, 700 milliseconds after the onset of the word, the target and distractor pictures were presented side-by-side during 1,000 milliseconds until the end of the trial. After this, the attention getter of the next trial was immediately presented. Each experimental session lasted approximately 10 minutes.

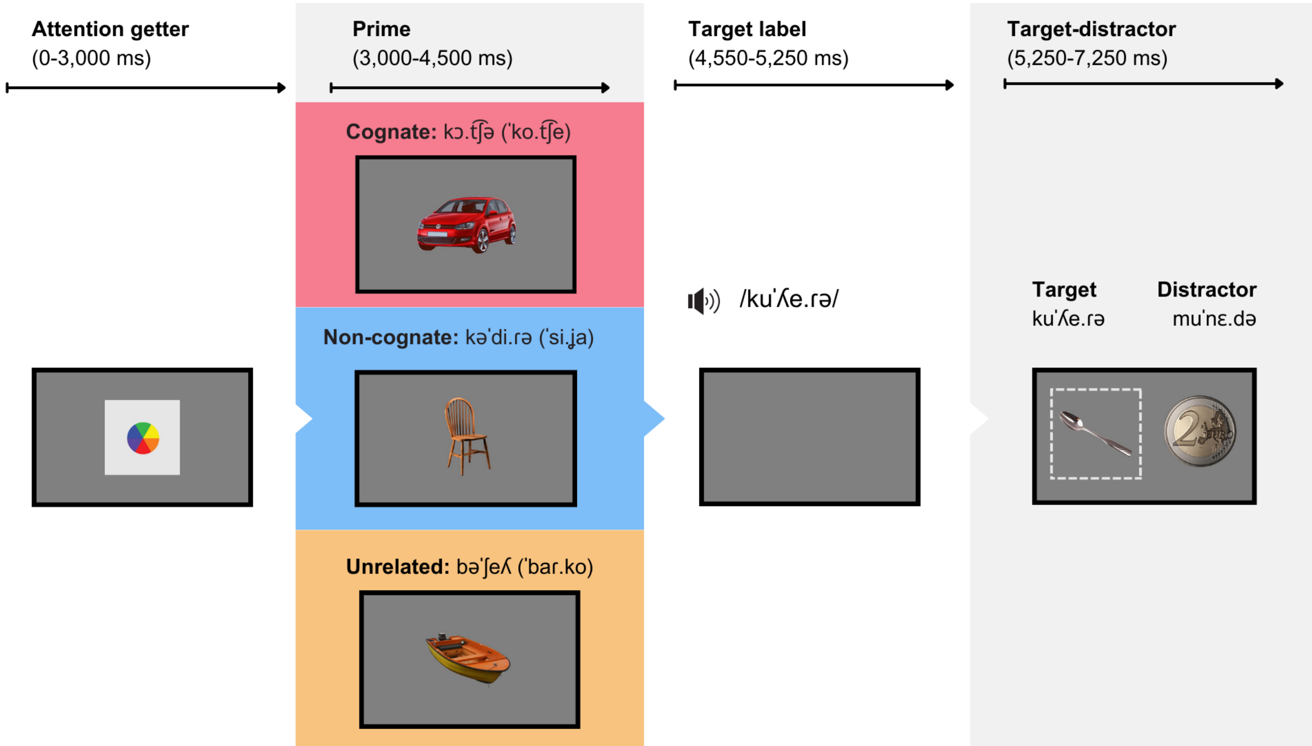

Figure 3.3: Experimental task design with examples in Catalan. In each trial, the prime image is presented in silence for 1,500 ms. Then the auditory target label is presented, and finally the target and distractor pictures are presented side-by-side for 2,000 ms. In cognate trials (n = 8), Catalan *and* Spanish prime labels shared phonological onset with the target label. In non-cognate trials (n = 8), only the Catalan prime label shared phonological onset with the target label. In unrelated trials (n = 16), none of the prime labels shared phonological onset with the target label.

3.2.1.3 Stimuli

We created four lists of trials, across which the same target-distractor pair appeared with a different prime, counterbalancing the condition to which it belonged. For instance, in list one the *ball-trousers* pair was preceded by *bike* (*Related/Cognate*), by *butterfly* (*Related/Non-cognate*) in list two, and by *star* and *nose* (*Unrelated*) in lists three and four (see Section 3.5 for a detailed description of the stimuli). Table 3.2 shows a detailed summary of the stimuli properties, broken down by trial type and testing language. Trials included in each condition had equivalent length (number of phonemes) and lexical frequency. Lexical frequencies were extracted from the English corpora from the CHILDES database (MacWhinney, 2000; Sanchez et al., 2019) as counts per million words, and transformed into Zipf scores for easier cross-language comparison (Van Heuven et al., 2014; Zipf, 1945). Audios had an average duration of 864.23 ms (*SD* = 148.53, *Range* = 570–1,250).

Table 3.2: Summary of stimuli properties in Studies 1 and 2 by trial type. Values are summarised using the mean and the standard deviation (between parentheses).

	Word length (phonemes)		Lexical frequency (Zipf)		Familiarity (%)	
Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Study 1: English						
Related/Cognate	5.00 (1.24)	4.50 (1.34)	4.63 (0.53)	4.75 (0.39)	0.62 (0.10)	0.70 (0.15)
Related/Non-cognate	5.75 (2.72)	4.50 (1.34)	4.75 (0.18)	4.75 (0.39)	0.61 (0.13)	0.71 (0.15)
Unrelated	5.24 (2.27)	4.33 (1.47)	4.68 (0.38)	4.73 (0.38)	0.67 (0.18)	0.73 (0.17)
Study 2: Catalan						
Related/Cognate	4.50 (1.34)	4.88 (1.28)	5.07 (0.33)	4.83 (0.26)	0.85 (0.09)	0.69 (0.23)
Related/Non-cognate	4.88 (1.47)	5.17 (1.33)	5.01 (0.37)	4.76 (0.25)	0.83 (0.11)	0.70 (0.22)
Unrelated	5.00 (1.51)	4.98 (1.31)	4.91 (0.31)	4.89 (0.25)	0.76 (0.15)	0.68 (0.22)
Study 2: Spanish						
Related/Cognate	4.50 (0.88)	6.12 (1.55)	5.10 (0.31)	4.77 (0.29)	0.65 (0.24)	0.47 (0.24)
Related/Non-cognate	5.25 (1.21)	5.92 (1.54)	4.94 (0.42)	4.71 (0.26)	0.68 (0.21)	0.50 (0.26)
Unrelated	4.62 (1.06)	5.73 (1.53)	4.94 (0.28)	4.69 (0.23)	0.64 (0.23)	0.46 (0.27)

The auditory stimuli were natural exemplars of the selected target words, spoken by a Southern British English female speaker who was instructed to pronounce each word in a toddler-directed manner. We used the Audacity and Praat (Boersma & Van Heuven, 2001) software packages to trim, denoised, and normalised their amplitude. The visual stimuli were realistic photographic representations of a typical exemplars of the prime, target, and distractor words. Image backgrounds were removed from the original pictures using the GNU Image Manipulation Program (GIMP), resized to a rectangle of a maximum of 400 pixels height or wide, and finally placed in the centre of a 50% grey rectangle square of 500 $\times$ 500 pixels. The final stimuli had a resolution of 72 dpi. When presented in the eye-tracker screen, the areas of interest (AOI) occupied an area of 13.23 $\times$ 13.23 cm (11.613° visual angle from participants' perspective).

3.2.1.4 Procedure

Testing took place in a sound-proof room at the BabyLab of the University of Oxford. Participants sat on their caregivers' lap in a dimly lit testing booth while the experimenter conducted the experiment from outside. Caregivers were instructed to keep their eyes shut (to avoid recording their gaze, instead of the participant's), to be still, and to avoid interacting with the participant verbally or non-verbally. Participants sat at approximately 65 cm from the eye-tracker and a 23-inches screen with 1929×1080 resolution. The study was run on Windows 7 (64-bit), using a custom Matlab script, PresentMate, based on the PsychToolbox-3 extension (3.0.10, 32 bit) (Brainard & Vision, 1997; Kleiner et al., 2007; Pelli & Vision, 1997). Visual fixations were recorded using a Tobii TX300 eye-tracker (Tobii Technology, Stockholm, Sweden) and a 23-in screen of 1920 $\times$ 1080 resolution. The Tobii Analytics SDK 3.0 was used to interact with the eye-tracking while the experiment was running. Sampling rate was set at 120 Hz. A 9-point calibration was performed before every experimental session, in which the picture of a colourful beach ball was presented. We set a 55% grey background for the screen during calibration and stimuli presentation. Auditory stimuli were presented through two loudspeakers located behind the screen, one to each side. The experimenter monitored the experimental from outside the room using a centrally located video camera place above the screen. After a successful calibration the experimenter triggered the onset of the first trial. Trials were presented uninterruptedly and without intervention of the experimenter until the 32 trials were presented, or the experimental session had to be stopped because of the participant's behaviour.

3.2.1.5 Data analysis

Data processing. We defined a time window of interest from 200 ms after target and distractor pictures onset until the end of the trial at 2,000 ms when both pictures disappeared from screen. The first 200 ms of the test phase were discarded to avoid modelling fixations driven by processes other than auditory word recognition (Fernald et al., 1998, 2001). Missing eye-tracker samples were interpolated using the last-observation-carried-forward (see Zettersten et al., 2023 for a similar approach), with a maximum of 20 maximum consecutive missing samples being interpolated (an equivalent of 166.67). Target looking probability was calculated as the empirical logit, using the number of samples inside the time bin in which the participant was looking at the target and distractor AOI (see Equation 3.1) (Agresti, 2012; Barr, 2008), as follows:

$$\eta' = \ln\left(\frac{\text{Target} + 0.5}{\text{Distractor} + 0.5}\right) \tag{3.1}$$

We gathered data from 3,484 trials from 110 testing sessions, generated from 97 distinct participants. We excluded trials in which participants failed to provide 50% valid eye-tracking samples (equivalent to 750 ms) during the prime phase (n = 829) or 50% valid samples (equivalent to 1,000 ms) during the target-distractor phase (n = 650). We also excluded trials in which participants did not provide at least 5% of valid samples (equivalent to 100 ms) of target or distractor looking in the test phase (n = 1,003) (see Floccia et al., 2020; Mani et al., 2012 for a similar approach).

After trials that matched any of the aforementioned exclusion criteria from the data set, we excluded participants who did not provide at least two valid trials in each condition (n = 19), and participants with a vocabulary size lower than 42, which corresponds to 10% of the words in the OCDI vocabulary checklist (n = 3). The final data set included 1,861 trials from 78 testing sessions, generated by 79 distinct participants. Of those participants, 69 provided data from one experimental session, 10 provided data from two experimental sessions, and NA provided data from three experimental sessions. From the trials included in the final data set, 915 were *Unrelated* trials (502 previously excluded), and 946 were *Related* trials(470 previously excluded).

Modelling approach. We used Bayesian Hierarchical General Additive Models (HGAMs) to model the data (Pedersen et al., 2019), using a Gaussian distribution to model the the logit of target looking. First, we fit a model ($\mathcal{M}_0$) that included the main effects of *Condition* and *Age* as fixed effects in the model. We set an *a priori* contrast for the *Condition* predictor (Schad et al., 2020), comparing *Unrelated* and *Related* trials (sum-coded as `-0.5` and `+0.5`. Before entering the model, the *Age* predictor was standardised by subtracting from each observation the mean of the predictor, and dividing the result from the standard deviation of the predictor. We included the variable *Session*—which indexes individual testing sessions that may belong to the same participant—as grouping variable, nested within the *Participant* grouping variable—which indexes a distinct participant. This nested random effects structure incorporates the longitudinal design of data collection, in which multiple participants were tested more than once at different ages. We added by-session intercepts and *Condition* slopes, and by-participant intercepts and *Age* slopes. To model the time course of target looking across time bins, we included B-splines for the main effect of *Time*, and for the *Condition* predictor (Wood, 2017). For both splines, we specified $k = 8$ basis functions or *knots*. Equation 3.2 shows a formal implementation of the model. We implemented this model using `brms` (Bürkner, 2017), an R interface to the Stan probabilistic language (2.33.0) (Carpenter et al., 2017). We ran two iteration chains using the by-default No U-Turn Sampler algorithm with 1,000 iterations each and an additional 1,000 warm-up iterations per chain.

$$
\begin{aligned}
&\textbf{Target looking by participant } i \textbf{ in session } j\\
y_{ij} &\sim \mathcal{N}(\mu_{ij}, \sigma_{ij})\\
\\
&\textbf{Distributional parameters:}\\
\eta'(\mu_{ij}) &= (\beta_0 + u_{0_{ij}}) + (\beta_1 + u_{1_{ij}})\text{Condition} + \beta_2\text{Age} + \sum_{w=1}^{k} b_w \beta_{3_k}\text{Time}+\\
&\text{where:}\\
&\quad \eta' \text{ is the empirical logit of target fixations}\\
&\quad b_w \text{ is the cubic spline of the } w \text{ basis function}\\
&\quad k \text{ is the number of knots in the spline } (k = 8)\\
&\textbf{Prior:}\\
\beta_{0-3} &\sim \mathcal{N}(0, 0.5)\\
u_{0-1_{ij}} &\sim \mathcal{N}(0, \sigma_{0-2})\\
b_w &\sim \text{MVN}(0, \tau)\\
\sigma_{0-1}, \tau &\sim \text{Exponential}(6)\\
\rho_{0-1} &\sim LKJCorr(6)\\
&\text{where:}\\
&\quad \rho_{0-1} \text{ are the correlation parameters for } \sigma_{0-2}
\end{aligned}
\tag{3.2}
$$

3.2.2 Results

3.2.2.1 Priming effects

We tested the differences between the conditions of interest in two ways. First, we examined the posterior distribution of the regression coefficients of the linear predictors in model $\mathcal{M}_0$ (see Equation 3.2). We assessed the practical relevance of the coefficients following J. K. Kruschke & Liddell (2018). We specified a region of practical equivalence (ROPE) from -0.1 to +0.1, in the logit scale. This region indicates the range of values that we considered equivalent to zero. We then summarised the posterior distribution of each regression coefficient with the 95% highest density interval (HDI). This interval contains the true value of this coefficient with 95% probability, given the data. Finally, we calculated the proportion of posterior samples in the 95% HDI that fell into the ROPE, noted as $p(\text{ROPE})$, which indicates the probability that the true value of the regression coefficient falls into the ROPE (and therefore should be considered equivalent to zero). For example, $p(\text{ROPE}) = .80$ indicates that, given our data, there is a 80% probability that the true value of the coefficient falls within the ROPE, and can therefore be considered equivalent to zero.

Overall, the average participant' target looking time exceeded chance levels, as indicated by the fact that the 95% HDI of the intercept term excluded zero (β = 0.381, 95% HDI = [0.292, 0.464]) and all of its posterior samples fell outside of the ROPE. The 95% HDI of the coefficient of *Age* had a positive sign, but did not exclude zero (β = -0.023, 95% HDI = [-0.110, 0.058]), and overlapped completely with the ROPE, indicating that participants from all ages showed equivalent overall target word recognition. The 95% HDI of the contrast of the *Condition* predictor—comparing *Unrelated* and *Related* trials—included zero (β = 0.093, 95% HDI = [-0.035, 0.235]), and 50.07% of its posterior samples fell within the ROPE.

Second, we examined the differences between the priming conditions in the time course of the trial, incorporating the smooth functions of the HGAMs to generate marginal posterior predictions for each condition across for each time point. Figure 3.4 shows the posterior predictions of the model for each condition, and a summary of the difference between the *Unrelated* and *Related* conditions, at each time point to test the practical relevance of these differences, were compared their 95% HDI against the [-0.1, +0.1] ROPE. This analysis revealed a similar pattern of results to the previously shown: predicted target looking for the three conditions overlaps across the full time course of the trial.

3.2.2.2 Age and vocabulary size effects

To test our hypotheses regarding the role of age and vocabulary size on the emergence of priming effects, we compared the fit of model $\mathcal{M}_0$ against the fit of other models including the two-way interaction between *Condition* and *Age* ($\mathcal{M}_1$), or the two-way interaction between *Condition* and *Vocabulary* ($\mathcal{M}_2$), and all main effects involved. As with *Age*, the *Vocabulary* predictor was standardised before entering the model. We compared the models using one-out cross-validation (LOO-CV) as a benchmark of model performance, using a Pareto-smoothed importance sampling (PSIS)

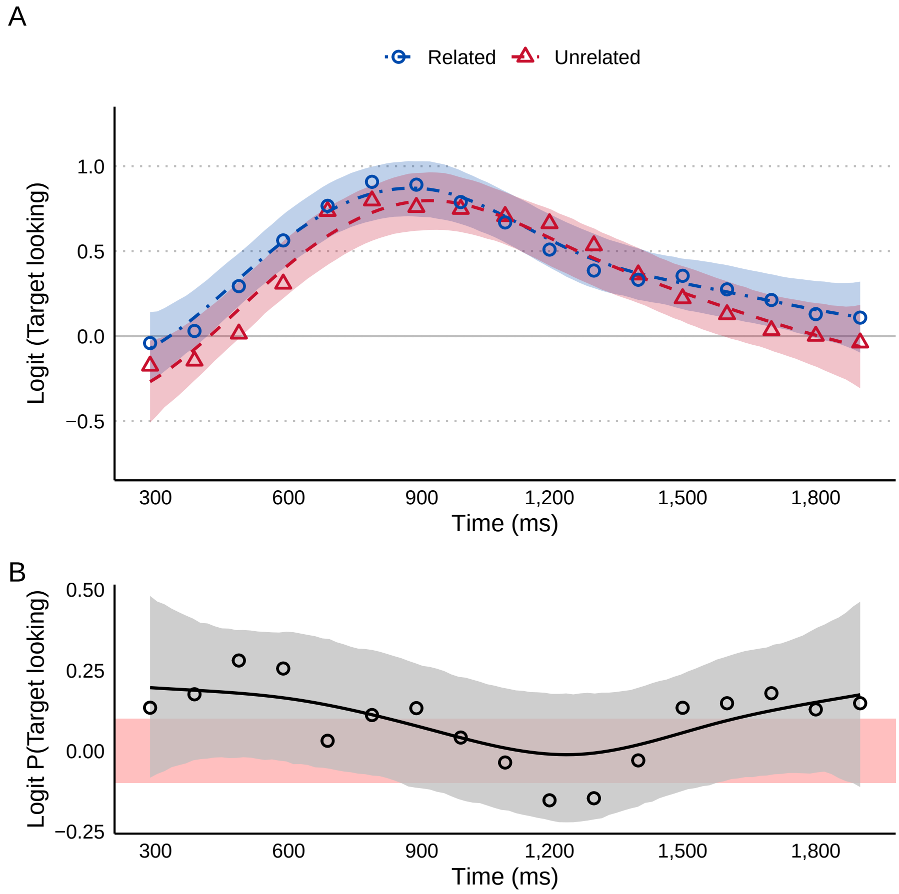

Figure 3.4: Time course of target fixations in Study 1. A) Posterior mean predictions of the time course of target fixation in the test phase. B) Posterior mean prediction of the time course of the differences in target looking time between conditions. Intervals represent the 95% CrI of the posterior predictions. Lines indicate the mean of the posterior predictions.

Table 3.3: Leave-one-out cross validation outcomes, comparing the predictive performance of the models in Study 1. $ELDP$: sum of expected log pointwise predictive density for a new data set. $ELDP_{SE}$: standard error of the $ELPD$, which indictes the uncertainty about the predictive performance for unknown future data. Δ: pairwise difference in $ELPD$ for two models. The difference is computed relative to the model with lowest $ELPD$ (best fitting model). Δ_{SE}: standard error of component-wise differences of *ELPD* between two models.

	Predictors	$ELDP$	$ELDP_{SE}$	Δ	Δ_{SE}
$\mathcal{M}_1$	Age $\times$ Condition	-8,469.02	73.01	-	-
$\mathcal{M}_0$	Age $+$ Condition	-8,469.15	73.02	-0.13	1.11
$\mathcal{M}_2$	Vocabulary $\times$ Condition	-8,469.37	73.09	-0.35	1.58

approximation (Vehtari et al., 2017). A better performance by models $\mathcal{M}_1$ or $\mathcal{M}_2$ over $\mathcal{M}_0$ would point to *Age* or *Vocabulary*, respectively, playing a substantial role in participants' word-recognition, or on the emergence of priming effects. Table 3.3 shows a summary of the predictive performance of the models, as quantified by the expected log-predictive density (*ELPD*), and its standard error (*SE*, a measure of uncertainty around the *ELPD*). Overall, all models, performed equivalently, as shown by the small difference in *ELPD*, relative to the uncertainty of the estimates. This suggests that participants' target looking during the test phase can be predicted with relative accuracy without taking into account the age or vocabulary size of the participants.

3.2.3 Discussion

We found strong evidence of successful word recognition across participants of all ages, but we did not observe any evidence of phonological priming. English monolingual participants from all ages showed an equivalent pattern of target looking in both *Related* and *Unrelated* trials. In conclusion, we failed to replicate the original studies by Mani & Plunkett (2010) and Mani & Plunkett (2011a). The absence of a phonological priming effect suggest that either English monolinguals did not generate implicit labels for the prime pictures presented in silence, or that, if generated, such labels did not interact with the subsequent recognition of the target word. Both explanations conflict with both Mani and Plunkett's studies, and also with previous studies suggesting that infants 12-months and older already generate internal labels when presented with pictures of familiar objects (Duta et al., 2012; Styles et al., 2015).

Adding the predictors *Age* or *Vocabulary size* as predictors in the model, in interaction with *Condition* did not increase the fit of the model. This points to neither variable having a substantial influence in participants' target looking behaviour across conditions. These results diverge from previous studies reporting an increment in word recognition speed (Fernald et al., 1998; Marchman & Fernald, 2008), and stronger phonological priming effects in children with larger vocabulary sizes (Avila-Varela et al., 2021;

Chow et al., 2017; Mani & Plunkett, 2011a). Overall, this results suggest that our modification of the implicit naming task resulted in the loss of the originally reported effect.

3.3 Study 2

The original planning of the present investigation was to run Study 1 first and once the procedure had been validated to start Study 2. However, right at the beginning of data collection, the outbreak of COVID-19 pandemic took place. At this point it was decided to run both experiments in parallel. Data collection at the Barcelona site proceeded at a faster rate than at Oxford. It was not until data collection was well advanced in Barcelona that the results of study 1 were available. This is the reason why Study 2 was run with the same procedure as Experiment 1.

3.3.1 Methods

3.3.1.1 Participants

We collected data from 162 children living in the Metropolitan Area of Barcelona (Spain), tested at the Laboratori de Recerca en Infància at the Universitat Pompeu Fabra. Families were recruited from maternity rooms in private hospitals and social media, and contacted via phone when the child's age spanned between 20 and 32 months. From the 162 children that participated, 81 participated once, 55 participated twice, and 26 participated three times. Recurrent participants were tested with at least 2.06 months of difference. We gathered a total of 269 testing sessions. Participants were divided into monolinguals and bilinguals based on their relative degree of exposure to Catalan and Spanish, estimated using an adaptation of the Language Exposure Questionnaire (LEQ, Bosch & Sebastián-Gallés, 2001). We categorised participants as monolingual if exposed to more than 80% or more of the time to their dominant language, and as bilingual otherwise. Eighty of the participants were categorised as monolinguals (34 female, 48 male) and 83 as Catalan/Spanish bilinguals (49 female, 34 male) (see Table 3.1 for a detailed summary of participants' age and language profile). Participants' vision was normal, none used glasses or any other type of vision corrector.

We collected vocabulary data using parental responses to the Barcelona Vocabulary Questionnaire (BVQ, Garcia-Castro et al., 2023), an online vocabulary checklist developed to assess the vocabulary size of Catalan-Spanish bilingual toddlers, and inspired in several adaptations of the the Communicative Developmental Inventory (CDI, Fenson et al., 1994). This questionnaire has four versions, each including a different but overlapping subset of words, from a total pool of 542 words from 26 functional-semantic categories. Each version included a Catalan and a Spanish vocabulary checklist. Catalan checklists contained between 343 and 349 words, and Spanish checklists contained between 349 and 349 words (see the Methods section of Chapter 1 for a detailed description of the questionnaire). Participants were randomly allocated to one of the four versions. Recurrent participants were always allocated to the same version. Families received a link to the BVQ immediately after each experimental session, and were given two weeks to fill it. It is common for children living in the Metropolitan area of Barcelona to be exposed to both Catalan and Spanish in some degree, even monolinguals. For this reason, we collected Catalan *and* Spanish vocabulary data from all participants in Study 2, but for consistency with Study 1, we calculated vocabulary sizes for participants in Study 2 as the number of words that caregivers reported their child to *understand* or *understand and say* only in the dominant language of the child (i.e., the language of test).

One hundred thirty-six (51%) families failed to provide a complete response to the vocabulary checklist within the two-week time limit. We imputed missing vocabulary size scores using single imputation, taking the vocabulary size scores of a pool of 542 additional participants for which a successful response for the questionnaire had been gathered. We used participants' age in months and their language profile (monolingual or bilingual) as predictors. We used the `mice` R package (Van Buuren & Groothuis-Oudshoorn, 2011) to perform imputation using the Bayesian linear regression method (see Section 3.6).

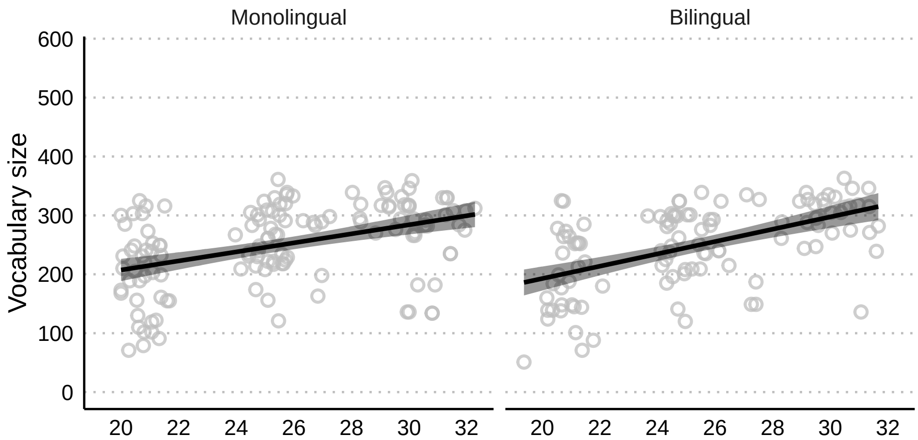

Figure 3.5: Participant receptive vocabulary sizes across ages and language profiles in Study 2. For descritive purposes, mean and standard error of the mean are indicated, as calculated using a linear regression model.

3.3.1.2 Design

Participants were presented with 32 trials in random order, which belonged to three conditions: *Unrelated* trials (*n* = 16), *Related/Non-cognate* (*n* = 8), and *Related/Cognate* (*n* = 8). In *Unrelated* trials, the target label shared phonological onset with the Catalan and Spanish labels of the prime picture (e.g., prime: /ˈgos/$_{\text{CAT}}$–/ˈpe.ro/$_{\text{SPA}}$[dog], target: /ˈka.za/$_{\text{CAT}}$[house], for a child tested in Catalan). In *Related/Non-cognate* trials, the target shared phonological onset with the prime label in the test language, but not with the prime label in the other language (e.g., prime: /**m**iˈʤo/$_{\text{CAT}}$ (/kal.θeˈin/$_{\text{SPA}}$)[dog], target: /**m**uˈnɛ.ðə/$_{\text{CAT}}$[coin]). In *Related/Cognate* trials, the target shared phonological overlap with both English and Spanish prime labels (e.g., prime: /ˈ**a**brə/$_{\text{CAT}}$–/ˈ**a**r.βol/ $_{\text{SPA}}$)[tree], target: /əˈβɛ.jə/_{CAT} [bee]$).

3.3.1.3 Stimuli

We created six stimuli lists: three in Catalan, and three in Spanish. Lists were created following the same constraints as in Study 1, but now considering the cross-linguistic phonological relationship between Catalan and Spanish. Extracting lexical frequencies from the Catalan and Spanish corpora in the CHILDES database was not possible, given the low number of participants and tokens included. We mapped the English lexical frequencies onto their Catalan and Spanish translation equivalents (see Fourtassi et al., 2020 and Chapter 2 for similar approaches). The auditory stimuli were natural exemplars of the selected target words, spoken by a proficient female bilingual speaker of Catalan (Central variety) and Castilian Spanish, who was instructed to pronounce each word in a toddler-directed manner. Catalan audios had an average duration of 1,229.84 ms (*SD* = 171.43, *Range* = 860–1,550), and Spanish audios had an average duration of 1,080.47 ms (*SD* = 134.58, *Range* = 830–1,390). New visual stimuli were created to accommodate the words included in the new stimuli lists, and possible cultural differences in the typicality of the exemplars shown in the pictures (see Section 3.5 for a detailed description of the stimuli).

3.3.1.4 Procedure

Same as in Study 1. We run the study on Windows 10 64-bit, using custom Matlab (2018a 64-bit) script using the PsychToolbox-3 extension (3.0.15 64-bit) to present the stimuli on a 23-inches screen with 1929×1080 resolution, and the Tobii Analytics SDK 3.0 to interact with the eye-tracker (Tobii TX300 and Tobii Pro Sprectrum, Tobii Technology, Stockholm, Sweden) while the experiment was running.

3.3.1.5 Data analysis

Data processing. We gathered data from 8,608 trials from 269 testing sessions, generated from 162 distinct participants. We excluded trials in which participants failed to provide 50% valid eye-tracking samples (equivalent to 750 ms) during the prime phase (*n* = 1,815) or 50% valid samples (equivalent to 1,000 ms) during the target-distractor phase (*n* = 1,262). We also excluded trials in which participants did not provide at least 10% of valid samples (equivalent to 100 ms) for both the target *and* the distractor (*n* = 2,461).

After excluding trials that matched any of the aforementioned criteria from the data set, we excluded participants who did not provide at least two valid trials in each experimental condition (*n* = 29), and participants with a dominant-language vocabulary size lower than 10% (which depending on the version of the vocabulary questionnaire they were allocated to, varied from 34 and 37) (n = 0). The final data set included 5,072 trials from 240 testing sessions, generated by 151 distinct participants. Of those participants, 81 provided data from one experimental session, and 51 provided data from two experimental sessions.

Modelling approach. We modelled the data following a similar approach as in Study 1, with the main difference that participants' language profile (*Group*) was now included as a predictor in the model, in interaction with the *Condition* predictor. We set two *a priori* contrasts for the *Condition* predictor: one comparing *Unrelated* and *Related/Non-cognate* trials (sum-coded as `-0.5` and `+0.5`, with *Related/Cognate* trials coded as `0`), and another comparing *Related/Non-cognate* and *Related/Cognate* trials (sum-coded as `-0.5` and `+0.5`, with *Unrelated* trials coded as `0`). In Study 2, the base model $\mathcal{M}_0$ included the the main effects of *Age*, *Condition*, and *Group*, and the two-way interaction between the *Condition* and *Group* predictors. Contrast coding of the *Condition* predictor was the same as in Study 1. We set one *a priori* contrasts for the *Group* predictor, comparing *Monolingual* with *Bilingual* participants (sum-coded as `-0.5` and `+0.5`, respectively). To model the time course of target looking, we included B-splines for the main effect of *Time*, and for the two-way interaction between *Condition* and *Group*.

Statistical inference. Same procedure as in Study 1.

3.3.2 Results

3.3.2.1 Priming effects

Overall, the average participants' looking time exceeded chance levels, as indicated by the fact that the 95% HDI of the intercept term excluded zero (β = 0.215, 95% HDI = [0.176, 0.256]), and that all of its posterior samples fell outside of the ROPE. The coefficient of *Age* had a positive sign, but its 95% HDI overlapped completely with the ROPE (β = 0.025, 95% HDI = [-0.013, 0.064]), indicating that participants from all ages showed equivalent overall target word recognition. The 95% HDI of the coefficient of *Group* also included zero (β = -0.014, 95% HDI = [-0.100, 0.066]) and completely overlapped with the ROPE, indicating an equivalent overall target preference in monolinguals and bilinguals,

The 95% HDI of the first contrast of the *Condition* predictor—comparing *Unrelated* and *Related/Non-cognate* trials—included zero (β = 0.058, 95% HDI = [-0.033, 0.143]), and 75.73% of its posterior samples overlapped with the ROPE. The 95% HDI of the second contrast, comparing *Related/Non-cognate* and *Related/Cognate* trials, also included zero (β = -0.011, 95% HDI = [-0.121, 0.092]), and 90.16% of its posterior samples overlapped with the ROPE. The overall target preference was equivalent across both pairwise condition comparisons. The interaction term between the first *Condition* contrast contained zero (β = -0.013, 95% HDI = [-0.182, 0.157]), with 59.00% of its posterior samples overlapping with the ROPE. The interaction term between the second *Condition* contrast also contained zero (β = 0.093, 95% HDI = [-0.106, 0.301]), and 75.73% of its posterior samples fell within the ROPE. The outcomes of this model provide strong evidence against differences between monolinguals and monolinguals, and inconclusive evidence for differences in overall target looking time across conditions.

An analysis of the time course of target looking revealed a similar pattern of results (see Figure 3.6). Posterior mean prediction for the three conditions overlap across the full time course of the trial in both language groups.

3.3.2.2 Age and vocabulary size effects

A comparison between models including *Age* ($\mathcal{M}_1$), *L1 vocabulary* ($\mathcal{M}_2$), and *Total vocabulary* ($\mathcal{M}_3$) against model $\mathcal{M}_0$, which only included *Age* as a main effect is shown in Table 3.4. Overall, all models performed equivalently, with the model $\mathcal{M}_2$ showing slightly better performance. The equivalent performance of all models suggests that participants' target looking during the test phase can be predicted with relative accuracy

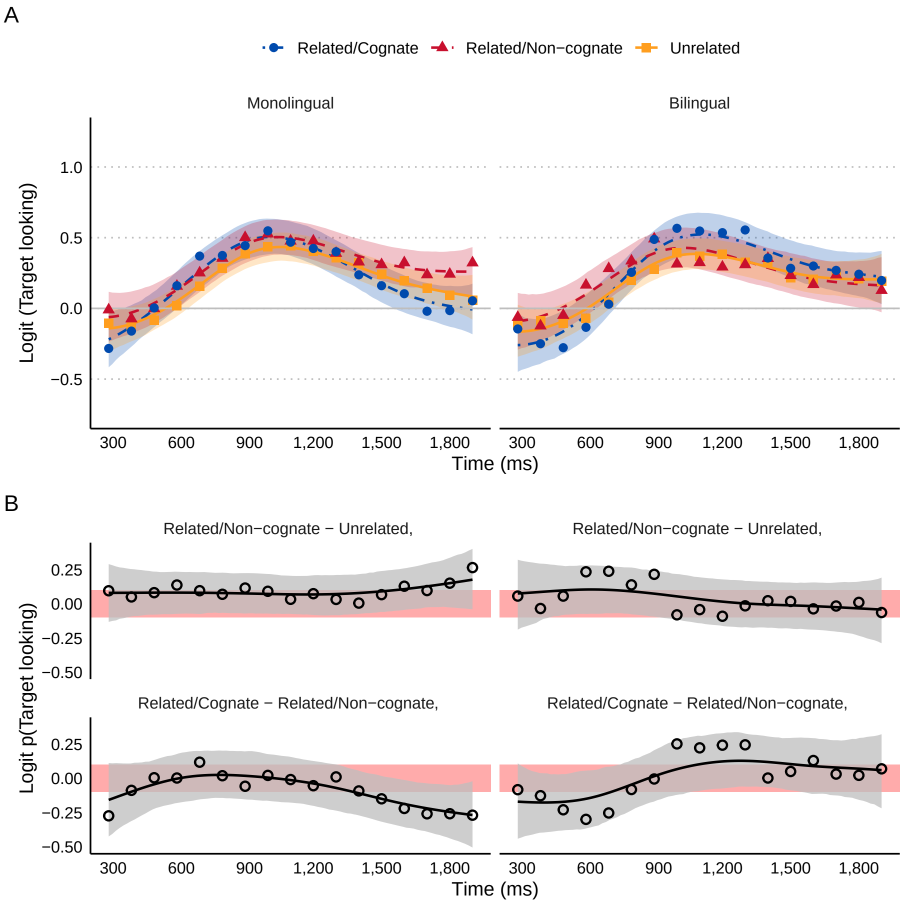

Figure 3.6: Time course of target fixations in Study 2. A) Posterior mean predictions of the time course of target fixation in the test phase. B) Posterior mean prediction of the time course of the differences in target looking time between conditions. Intervals represent the 95% CrI of the posterior predictions. Lines indicate the mean of the posterior predictions.

Table 3.4: Leave-one-out cross validation outcomes, comparing the predictive performance of the models in Study 1. $ELDP$: sum of expected log pointwise predictive density for a new data set. $ELDP_{SE}$: standard error of the $ELPD$, which indictes the uncertainty about the predictive performance for unknown future data. Δ: pairwise difference in $ELPD$ for two models. The difference is computed relative to the model with lowest $ELPD$ (best fitting model). Δ_{SE}: standard error of component-wise differences of *ELPD* between two models.

	Predictors	$ELDP$	$ELDP_{SE}$	Δ	Δ_{SE}
$\mathcal{M}_1$	Age $\times$ Condition	-8,469.02	73.01	-	-
$\mathcal{M}_0$	Age + Condition	-8,469.15	73.02	-0.13	1.11
$\mathcal{M}_2$	Vocabulary $\times$ Condition	-8,469.37	73.09	-0.35	1.58

without taking into account *L1 vocabulary*, or *Total vocabulary* sizes. We now report the median and 95% HDI of the coefficients of $\mathcal{M}_2$, the best-fitting model.

3.3.3 Discussion

Paralleling the results from Study 1 participant' looking behaviour suggested robust word recognition, regardless of experimental condition, participant language profile, age, or vocabulary size. Monolinguals and bilinguals showed equivalent target looking behaviour in *Unrelated*, *Related/Non-cognate*, and *Related/Cognate* trials, suggesting that no phonological priming took place, either within languages or across languages. These results contrast with those of previous studies using a similar paradigm, which reported within-language priming effects in same-aged monolinguals (Avila-Varela et al., 2021; Mani & Plunkett, 2011a) and younger (Duta et al., 2012; Mani & Plunkett, 2010; Styles et al., 2015), and cross-language priming in adults (Von Holzen & Mani, 2014).

We anticipated participants' sensitivity to phonological priming to increase with the size of their lexicon, in the light of previous studies in which the maturation of the lexicon was associated with larger phonological interference in word recognition (Chow et al., 2017; Mani & Plunkett, 2011a). In Study 2, incorporating participants' age as a predictor in the model in interaction with the two contrasts of the *Condition* predictor did not increase the predictive performance of the model. Neither did vocabulary size. This suggests that the lack of evidence of phonological priming in participants in this study, either within or across languages, did not depend of participants lexical development status.

3.4 General discussion

In this chapter, we investigated the developmental trajectories of cross-language co-activation in the initial lexicon. We tested a large cohort of monolingual and bilingual toddlers in an implicit naming paradigm, in which we designed three experimental conditions to manipulate the phonological overlap between the prime and target words within and across languages. In Unrelated trials, prime and target were phonologically unrelated in both languages. In Related/Non-cognate trials, prime and target labels shared phonological onset only in the dominant language of participants, in which they were tested. In Related/Cognate trials, the prime label was a cognate: prime and target labels shared phonological onset in both languages. In Study 1, we attempted to replicate the original findings by Mani & Plunkett (2010) and Mani & Plunkett (2011a) in a same-aged English monolingual cohort. We found no evidence of phonological priming. In Study 2, we tested a cohort of monolingual and bilingual infants learning Catalan, Spanish, or both, and found similar results, with no evidence of phonological priming effect in either monolinguals or bilinguals. We did not find any effect of participants' age or vocabulary size.

The lack of priming effects in Studies 1 and 2 contrasts with previous findings of within- and cross-language priming using an implicit naming paradigm. In their seminal study, Mani & Plunkett (2010) and Mani & Plunkett (2011a) reported within-language priming effects in English monolingual infants. In bilinguals, evidence of cross-linguistic priming in a implicit naming paradigm was available in adults (Von Holzen & Mani, 2014). The priming effects shown in these studies reveal that infants and adults retrieve phonologically detailed word-forms when presented with pictures of familiar objects, which later interact with the subsequent auditory recognition of phonologically related words. Evidence of such implicit naming is available in infants as young as 14 months. Electrophysiological evidence reported by Duta et al. (2012) and Styles et al. (2015) suggests that, at this, age, infants lexicalise name-known pictures presented in silence, and that the generated phonological form is sensitive to subsequent mispronunciations of the word. The possibility that infants in the present investigation failed to retrieve phonological word forms is therefore unlikely.

We consider three scenarios under which implicit naming might have occurred in the experiments presented in this chapter, but our design failed to capture it. First, it is be possible that infants in both Studies 1 and 2 implicitly generated phonological labels for the primes, but such labels lacked the phonological detail to interact with the subsequent recognition of a phonologically related target word. This is unlikely, given that both monolinguals (Bailey & Plunkett, 2002; Swingley & Aslin, 2000; Tamási et al., 2017) and bilinguals (Ramon-Casas et al., 2009; Tamási et al., 2016) have been shown to encode lexical representations with high phonological detail from early ages.

A second possibility is that participants successfully retrieved a detailed phonological form of the prime labels, but such forms failed to interact with target recognition. This would be explained by the lack of strong associations between phonologically related lexical representations at these ages. But even if one considers the possibility that participants in Study 1 failed to show priming effects for this reason (for instance, the emergence of phonological associations might follow different trajectories in Catalan-Spanish infants, compared to English infants), the fact that English monolingual infants in Study 2 failed to show such priming effects contradicts previous findings on the same population, reporting priming phonological priming effects in even younger infants (Mani & Plunkett, 2010, 2011a).

Third, and most likely, the modifications of the implicit naming task in the present investigation might have reduced the chances of detecting the anticipated effects. The most critical difference between the original design of the implicit naming task by Mani and Plunkett and that of the present study is the absence of a pre-naming phase during the test phase. Target auditory labels were presented immediately after the offset of the prime picture. It is possible that such time interval was too short for participants to retrieve the phonological label of the prime picture before the target was presented. Such failure to generate phonological word-forms for prime labels would have prevented participants in Studies 1 and 2 from being affected by phonological priming effects during target word recognition.

A difference in the difficulty of the stimuli might have influenced the results in the present study, compared to those of the original studies.

When designing the stimuli lists, we considered three variables as indices of word difficult during recognition: lexical frequency, age of acquisition, and number of phonemes. The distribution of the three variables was equivalent across the three experimental conditions (see Table 3.2), so it is unlikely that such differences cancelled out a possible priming effect. However, the stricter limitations under which we build the stimuli lists, might have lead to out stimuli lists including more difficult words than in the original study by Mani & Plunkett (2010). We examined this possibility by comparing the distributions of the English words included in Study 1, with those included in Mani & Plunkett (2010) and Mani & Plunkett (2011a) (stimuli lists are identical in both studies). **?@fig-mp** shows a comparison between the stimuli lists of the three studies in lexical frequency and word familiarity at 18 months. Overall, words included in Mani and Plunkett and in Study 1 have equivalent lexical frequency, and are know by a similar proportion of English monolinguals infants, according to the OCDI norms. This is the case for prime and target words across the related and the unrelated conditions. It is therefore unlikely that the lack of priming effects in Study 1 is due to an increased difficulty in the items included.

Another possibility is that participants in the present study had smaller vocabulary sizes than those of participants in the original studies. This hypothesis is not easy to investigate, as quantitative vocabulary sizes were not reported in original studies. A more recent study by Avila-Varela et al. (2021), in which phonological priming effects were found associated with participants vocabulary size, did provide summary statistics for participants vocabulary size scores. This study tested a cohort of monolingual German infants in a word recognition task, in which participants in which participants were presented with auditory primes and targets, which were phonologically related or unrelated. The authors estimated participants' receptive vocabulary sizes using the *Fragebogen zur frühkindlichen Sprachentwicklung* (Szagun et al., 2009), an adaptation of the CDI to German. Their cohort of participants showed receptive vocabulary sizes larger than those of participants in the present study. Participants in Avila-Varela et al. (2021) knew an average of 405.24 (*SD* = 96.29) at 21 months and 501.97 (*SD* = 73.41) at 24 months, which contrast with receptive vocabulary sizes of participants in Study 1: 293 at 21 months (*SD* = 71.24), and 304.33 (*SD* = 134.63) at 25 months.

In summary, we aimed to test the language non-selective hypothesis of lexical access in bilingual toddlers using an adaptation of the implicit naming paradigm. This adaptation involved target auditory labels immediately after the offset of prime pictures, instead of presenting the target labels after a baseline period of 2,000 after the offset of the prime pictures. In Study 1, we tested English monolinguals (same population as in the original studies) to establish a baseline to later test bilingual participants. We attempted to replicate the previously reported within-language phonological priming effect. We did not find evidence of such effect, suggesting that our modification of the original task was unsuccessful. Because data collection was conducted simultaneously for Studies 1 and 2, data in Catalan-Spanish monolinguals and bilinguals was available despite the failed replication in Study 1. In Study 2, we also found null pattern of results, in which neither monolinguals nor bilinguals showed evidence of within- or cross-language priming effects. Overall, our results suggest that the change in the timing of the trial disrupted the dynamics of word recognition in such way that priming effects were no longer detectable in our adaptation of the paradigm.

3.5 Appendix D: Stimuli lists

Table 3.5: Stimuli lists for each language. The condition to which the prime belonged is indicated between parentheses. *R/C*: Related/Cognate, *R/N*: Related/Non-cognate, *U*: Unrelated.

		Prime			
	Target-Distractor	List 1	List 2	List 3	List 4
English					
1	ball-trousers	nose (U)	star (U)	bike (R/C)	butterfly (R/N)
1	trousers-ball	train (R/C)	tree (R/N)	monkey (U)	penguin (U)
2	balloon-snail	phone (U)	helicopter (U)	boot (R/C)	brush (R/N)
2	snail-balloon	potato (U)	door (U)	sofa (R/C)	slide (R/N)
3	bird-milk	boot (R/C)	brush (R/N)	phone (U)	helicopter (U)
3	milk-bird	moon (R/N)	jacket (U)	jacket (U)	mask (R/C)
4	biscuit-pencil	bike (R/C)	butterfly (R/N)	nose (U)	star (U)
4	pencil-biscuit	plate (R/C)	pig (R/N)	hat (U)	sun (U)
5	box-pen	butterfly (R/N)	nose (U)	star (U)	bike (R/C)
5	pen-box	hat (U)	sun (U)	plate (R/C)	pig (R/N)
6	bread-fish	brush (R/N)	phone (U)	helicopter (U)	boot (R/C)
6	fish-bread	flower (R/C)	fireengine (R/N)	bottle (U)	book (U)

7	bucket-mouse	helicopter (U)	boot (R/C)	brush (R/N)	phone (U)
7	mouse-bucket	jacket (U)	mask (R/C)	mask (R/C)	moon (R/N)
8	bunny-nappy	star (U)	bike (R/C)	butterfly (R/N)	nose (U)
8	nappy-bunny	tomato (U)	tomato (U)	tomato (U)	tomato (U)
9	chair-fork	tiger (U)	chocolate (R/C)	chocolate (R/C)	chicken (R/N)
9	fork-chair	book (U)	flower (R/C)	fireengine (R/N)	bottle (U)
10	cheese-sock	chocolate (R/C)	chicken (R/N)	chicken (R/N)	tiger (U)
10	sock-cheese	door (U)	sofa (R/C)	slide (R/N)	potato (U)
11	chips-peas	chicken (R/N)	tiger (U)	tiger (U)	chocolate (R/C)
11	peas-chips	pig (R/N)	hat (U)	sun (U)	plate (R/C)
12	foot-teddy	fireengine (R/N)	bottle (U)	book (U)	flower (R/C)
12	teddy-foot	monkey (U)	penguin (U)	train (R/C)	tree (R/N)
13	frog-spoon	bottle (U)	book (U)	flower (R/C)	fireengine (R/N)
13	spoon-frog	sofa (R/C)	slide (R/N)	potato (U)	door (U)
14	mouth-plane	mask (R/C)	moon (R/N)	moon (R/N)	jacket (U)
14	plane-mouth	sun (U)	plate (R/C)	pig (R/N)	hat (U)
15	sandwich-truck	slide (R/N)	potato (U)	door (U)	sofa (R/C)
15	truck-sandwich	tree (R/N)	monkey (U)	penguin (U)	train (R/C)
16	shoe-table	boat (U)	boat (U)	boat (U)	boat (U)
16	table-shoe	penguin (U)	train (R/C)	tree (R/N)	monkey (U)
Catalan					
1	abella-papallona	finestra (U)	ànec (R/N)	arbre (R/C)	-
1	papallona-abella	pilota (R/C)	guitarra (U)	poma (R/N)	-
2	aigua-bolet	arbre (R/C)	camió (U)	ànec (R/N)	-
2	bolet-aigua	claus (U)	barret (R/N)	vaca (R/C)	-
3	aixeta-ungla	camió (U)	arbre (R/C)	finestra (U)	-
3	ungla-aixeta	peix (U)	peix (U)	ocell (R/N)	-
4	amanida-berenar	ànec (R/N)	finestra (U)	camió (U)	-
4	berenar-amanida	vaca (R/C)	osset (U)	barret (R/N)	-
5	bici-porta	barret (R/N)	claus (U)	osset (U)	-
5	porta-bici	guitarra (U)	pilota (R/C)	maduixa (U)	-
6	boca-orella	osset (U)	vaca (R/C)	claus (U)	-
6	orella-boca	plàtan (U)	plàtan (U)	peix (U)	-
7	caixa-porc	ampolla (U)	cadira (R/N)	cotxe (R/C)	-
7	porc-caixa	maduixa (U)	poma (R/N)	pilota (R/C)	-
8	casa-moneda	cotxe (R/C)	vaixell (U)	cadira (R/N)	-
8	moneda-casa	mitjó (R/N)	granota (U)	avió (U)	-
9	colom-mussol	cadira (R/N)	ampolla (U)	vaixell (U)	-
9	mussol-colom	moto (R/C)	avió (U)	mitjó (R/N)	-
10	cuc-formiga	vaixell (U)	cotxe (R/C)	ampolla (U)	-
10	formiga-cuc	formatge (R/N)	ulleres (U)	botó (U)	-
11	forquilla-got	ulleres (U)	formatge (R/N)	flor (R/C)	-
11	got-forquilla	gos (R/N)	pa (U)	mico (U)	-
12	fulla-galleda	botó (U)	flor (R/C)	ulleres (U)	-
12	galleda-fulla	mico (U)	gat (R/C)	pa (U)	-
13	galeta-pernil	gat (R/C)	mico (U)	gos (R/N)	-
13	pernil-galeta	flor (R/C)	botó (U)	formatge (R/N)	-

14	globus-onada	pa (U)	gos (R/N)	gat (R/C)	-
14	onada-globus	ovella (R/C)	ovella (R/C)	plàtan (U)	-
15	mà-ull	avió (U)	moto (R/C)	granota (U)	-
15	ull-mà	ocell (R/N)	ocell (R/N)	ovella (R/C)	-
16	mirall-planta	granota (U)	mitjó (R/N)	moto (R/C)	-
16	planta-mirall	poma (R/N)	maduixa (U)	guitarra (U)	-
Spanish					
1	bici-cepillo	botella (R/N)	globo (U)	mono (U)	-
1	cepillo-bici	cebra (R/C)	cerdo (R/N)	oreja (U)	-
2	boca-caja	vaca (R/C)	botella (R/N)	globo (U)	-
2	caja-boca	coche (R/C)	cama (R/N)	zumo (U)	-
3	botón-tobogán	globo (U)	mono (U)	vaca (R/C)	-
3	tobogán-botón	gato (U)	tren (R/C)	tenedor (R/N)	-
4	calcetín-plátano	pato (U)	coche (R/C)	cama (R/N)	-
4	plátano-calcetín	barco (U)	hoja (U)	pez (R/C)	-
5	cesta-tijeras	cerdo (R/N)	oreja (U)	mesa (U)	-
5	tijeras-cesta	tren (R/C)	tenedor (R/N)	casa (U)	-
6	cielo-pie	mesa (U)	cebra (R/C)	cerdo (R/N)	-
6	pie-cielo	perro (R/N)	barco (U)	hoja (U)	-
7	cubo-tambor	zumo (U)	pato (U)	coche (R/C)	-
7	tambor-cubo	casa (U)	gato (U)	tren (R/C)	-
8	cuchara-osito	cama (R/N)	zumo (U)	pato (U)	-
8	osito-cuchara	oveja (R/C)	ojo (R/N)	pelota (U)	-
9	gorrión-muñeca	gafas (R/N)	tomate (U)	zapato (U)	-
9	muñeca-gorrión	manzana (R/N)	vaso (U)	queso (U)	-
10	grifo-mariposa	galleta (R/C)	gafas (R/N)	tomate (U)	-
10	mariposa-grifo	moto (R/C)	manzana (R/N)	vaso (U)	-
11	guitarra-puerta	zapato (U)	galleta (R/C)	gafas (R/N)	-
11	puerta-guitarra	hoja (U)	pez (R/C)	perro (R/N)	-
12	gusano-martillo	tomate (U)	zapato (U)	galleta (R/C)	-
12	martillo-gusano	queso (U)	moto (R/C)	manzana (R/N)	-
13	hormiga-zanahoria	ojo (R/N)	pelota (U)	tele (U)	-
13	zanahoria-hormiga	oreja (U)	mesa (U)	cebra (R/C)	-
14	moneda-pierna	vaso (U)	queso (U)	moto (R/C)	-
14	pierna-moneda	pez (R/C)	perro (R/N)	barco (U)	-
15	ola-toro	pelota (U)	tele (U)	oveja (R/C)	-
15	toro-ola	tenedor (R/N)	casa (U)	gato (U)	-
16	ombligo-ventana	tele (U)	oveja (R/C)	ojo (R/N)	-
16	ventana-ombligo	mono (U)	vaca (R/C)	botella (R/N)	-

3.6 Appendix E: Imputing vocabulary sizes

Given the large number of participants in Study 2 whose families failed to fill in the vocabulary questionnaire in time, we imputed missing vocabulary sizes to avoid losing their data in subsequent analyses. We used the `mice` R package (Van Buuren & Groothuis-Oudshoorn, 2011) to perform single imputations via Bayesian linear regression. Figure 3.7 shows the distribution of observed and imputed vocabulary sizes. Overall, the distribution of imputed vocabulary sizes was equivalent to the distribution of observed vocabulary sizes of participants with similar age and language profile.

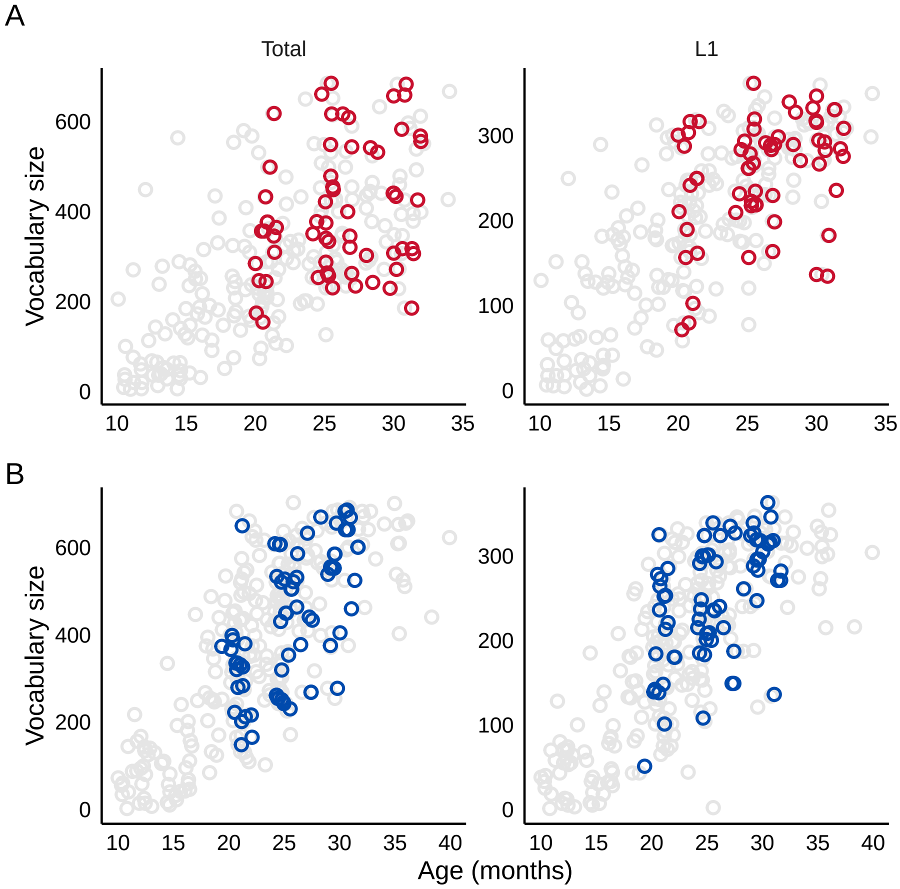

Figure 3.7: Imputation of missing receptive vocabulary size scores in Study 2 for monolinguals (A) and bilinguals (B). vocabulary size scores are epxressed in raw counts, that is, the number of words reported by caregivers as acquired. Vocabulary sizes were imputed from a larger sample of children who provided responses to the Barcelona Vocabulary Questionnaire. We used participants' age and language profile to impute scores of participants wih the same profile. Imputed observations are highlighted in red (monolinguals) and blue (bilinguals)

4 Discussion

The aim of the present thesis was to investigate the initial bilingual lexicon. We explored the role of cross-language lexical similarity on word acquisition, and its possible impact on the dynamics of lexical access. In this concluding chapter, we summarise the results from Chapter 2 and Chapter 3. We then elaborate on the implications of our findings on theoretical, and comment on some of the methodological limitations encountered. We also discuss possible steps to take in future research. We conclude highlighting the main contributions of the thesis.

4.1 Summary of results

In Chapter 2, we investigated how cognateness affects word acquisition in 10-to-32 month-old bilinguals learning Catalan and Spanish. We used Item Response Theory (IRT) to model the acquisition trajectories of a large sample of Catalan and Spanish words, and found a facilitation effect of cognateness on the probability of comprehension and production. This facilitation was mediated by an *ad hoc* index of word exposure, which adjusted the lexical frequency of the words for the dual linguistic input of bilinguals. Low-exposure words benefited more strongly from their cognate status, whereas words with average or high exposure were unaffected by their cognate status. We interpreted these results as evidence in favour of language non-selectivity playing a central role the initial lexicon. In particular, we suggested that exposure instances to words in one language contributed, to some extent as exposure instances to their translation equivalents (TEs).

Our account for the results found in Chapter 2 built on the assumption that bilingual infants co-activate the TEs in both languages, even during monolingual situations, in which they hear words in exclusively one of the languages. Previous experimental work on language non-selectivity in the initial lexicon relied on paradigms in which participants are presented with words from the two languages during the same testing session, introducing them into a bilingual context (Floccia et al., 2020; Jardak & Byers-Heinlein, 2019; Singh, 2014; Von Holzen & Mani, 2012). To our knowledge, no previous study had tested whether language non-selectivity takes place in fully monolingual paradigms. We addressed this gap in the literature in Chapter 3. We tested language non-selectivity in infants using an implicit naming paradigm, adapted from Mani and Plunkett (2010, 2011a). Participants were presented with an exclusively monolingual task. By manipulating the cognate status of prime words, and its impact on subsequent recognition of phonologically related words, we aimed to test whether participants co-activated TEs in both languages in monolingual situations. Methodological caveats in the adaptation of the task prevented us from draw conclusions from this experiment.

4.2 Towards a model of bilingual vocabulary growth

Differences in the developmental trajectories of word acquisition across bilingual populations have gained some attention in last decade. It had been previously established that, on average, bilingual infants learn words at a similar rate as monolinguals, despite facing a more challenging word-learning task (Bosch & Ramon-Casas, 2014; Byers-Heinlein et al., 2023; Core et al., 2013; Pearson et al., 1993; Pearson & Fernández, 1994; Poulin-Dubois et al., 2013). An influential monograph by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018) provided evidence for a possible mechanism behind bilingual word acquisition: bilingual toddlers learning two lexically similar languages (e.g., English-Dutch) show larger productive vocabularies than those learning two lexical, less similar languages (e.g., English-Mandarin). This suggested that some populations of bilinguals may exploit the similarities between their languages—particularly, the phonological similarity between TEs—to acquire words faster (see also Gampe et al., 2021). The authors pointed at the language non-selective hypothesis of lexical access as the mechanism behind this cross-language facilitation effect. How the dynamics of lexical access in the initial lexicon might relate to word acquisition was still to be addressed.

In Chapter 2, we explored the trajectories of acquisition of cognate and non-cognate words, and found an earlier age of the former—even after controlling for lexical frequency, relative language exposure, and word length—in line with previous findings by Mitchell et al. (2022). This facilitation effect was stronger in words to which participants were exposed less often. These results converge with two main predictions from our proposal. First, the earlier age-of-acquisition for cognates than for non-cognates is in line with a faster accumulation of learning instances for cognates. This might be the result of cognate words receiving stronger co-activation from their TEs than non-cognates. We suggest that this might have been driven by cognates receiving additional activation in a higher degree than than non-cognates, because of their higher phonological similarity. The asymmetry in the size cognateness facilitation effect between high-exposure and low-exposure words provides further support for this explanation. Words with lower lexical frequency or belonging to participants' less dominant language (in which they receive less input) should benefit more strongly from the additional co-activation provided by their (more frequently activated) translation, than higher exposure words, which might receive such additional co-activation less frequently. This mechanism may explain the facilitative role of lexical similar reported by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018), and the asymmetry found in the size of such effect between the English vocabulary and the additional-language vocabulary in their participants. Since English was the dominant language for most participants in their sample, it is possible that the increment in vocabulary size drive by cognates was stronger in the additional language, leading to a larger facilitation effect of lexical similarity. In summary, these results have important consequences for current models of bilingual lexical acquisition.

The present theoretical account makes an important contribution to the research on the bilingual lexicon. Few models of the bilingual lexicon have addressed the issue of early lexical acquisition. Instead, previous modelling efforts have mostly focused on word comprehension and production in the adult lexicon. Notable exemplars of models of the adult lexicon are the Revised Hierarchical Model (RHM) (Kroll & Stewart, 1994), the Bilingual Interactive Activation (BIA) model and its revised successor BIA+ (Dijkstra & Van Heuven, 2002, 2013), BIMOLA (Grosjean, 1988; Léwy, 2008), SOMBIT (Li et al., 2004; Li & Farkas, 2002), and BLINCS (Shook & Marian, 2013). The more recent proposal of the Multilink model (Dijkstra et al., 2019) integrates features of the RMH and BIA/BIA+ models to simulate a wide range of experimental observations in bilingual adults, spanning from the cognate facilitation effect in word recognition and production, as well as word translation. These models have provided valuable insight into the structure of the bilingual lexicon, and the underlying dynamics of word recognition and production, but have paid little attention to the developmental dimension of lexical acquisition. Other contributions, like the Ontogenic Model (Bordag et al., 2022; Gor et al., 2021), BIA-d (a more development-oriented extension of the BIA/BIA+ model, Grainger et al., 2010), have delved into the emergence and consolidation of lexical representations during second language acquisition, still through the lens of the adult lexicon. In summary, few studies have addressed the early bilingual lexicon.

One exception is the DevLex-II model by Zhao & Li (2007), a bilingual extension of DevLex (Li et al., 2007) focused on monolingual lexical development. This connectionist model describes how lexical representations emerge during the simultaneous acquisition of two languages, and how phonological similarity shapes the structure of the resulting lexicon. DevLex-II successfully generates plausible patterns of lexical growth. For instance TEs are mapped together in the simulations of this model, suggesting that the acquisition of words in one language is sensitive to the acquisition of their translations in the other, in line with previous findings (Bilson et al., 2015; R. K.-Y. Tsui et al., 2022). Simulations of word comprehension from DevLex-II also reveal within- and cross-language interference effect at the semantic and phonological levels, paralleling results in bilingual children: when the model was presented with a word, related semantic and phonological representations in both languages competed for selection (Zhao & Li, 2013). The case of cognate words was not addressed in this model.

In Chapter 2, we presented a model of bilingual lexical acquisition. We also discussed its predictions, and underlying assumptions. In the following paragraphs, we present a first iteration into the formalisation of this model, which we have entitled as the Accumulator Model of Bilingual Lexical Acquisition (AMBLA). As its name indicates, AMBLA extends the notion of *accumulator* to the bilingual case, borrowed from accumulator models of language acquisition (Hidaka, 2013; Kachergis et al., 2022; Mollica & Piantadosi, 2017). The central goal of AMBLA is to explain the two predictions tested in Chapter 2: that cognates are acquired earlier than non-cognates, and that this effect is stronger in the less-dominant language of the children. To explain how AMBLA works, we simulate the acquisition trajectories of two Catalan-Spanish TEs by a bilingual child learning Catalan and Spanish. The first TE is a cognate (/’gat/–/ˈga.to/ [cat]), and the second is a non-cognate (/ˈgos/–/ˈpe.roˈ/). For illustration purposes, we assume a scenario in which the child is exposed 60% of the time to Catalan (dominant language), and 40% of the time to Spanish (non-dominant language).

For each word-form, AMBLA generates an estimated age-of-acquisition. This value indicates the age at which some fixed proportion of the children in the target population (generally 50%) have acquired a word Piñeiro & Manzano (2000), according to caregivers' reports of word acquisition (e.g., Fenson et al., 1994, 2007), or the size of naming effects in word recognition paradigms (Marchman & Fernald, 2008; Marchman & Martínez-Sussmann, 2002). In AMBLA, the age-of-acquisition is defined as the age at which the child has accumulated a critical number of learning instances with the word-form. In the following simulations, we set this threshold at 300. This value was calibrated so that the scale of the model can be compared to the observed data in Chapter 2.

In AMBLA, the rate at which a child (i) accumulates leaning instances with a word form (j) is a multiplicative function of four variables (See Equation 4.1). First, the child's age (Age_i): the older the child, the more learning instances they accumulate with the word-form. for interpretability, we expressed the child's age in months in the simulation below. A second variable is the lexical frequency of the word-form (Frequency_j): the child will accumulate learning instances with more frequent words faster than with less frequent words. We assume that lexical frequency is a valid indicator of the amount of times child is exposed to a given word-form per unit of time, and that each exposure contributes one word learning instance[1]. We operationalised lexical frequency as the amount of times a

[1]Not all learning instances may be effective, as the mere exposure to a word-form may not result in the accumulation of information about the word and its referent. For simplicity, in the presented simulations we assumed that each exposure contributes one learning instance.

child may encounter a word-form in their speech input in the time span of a month. Given that this number of exposure instances may randomly vary from month to month, assumed a Poisson distribution to generate word exposure counts for each word-form in each month. For simplicity, we assume identical lexical frequency for all word-forms by assigning the same parameters for the Poisson distribution ($\lambda = 50$, which assumes that the child is most likely to encounter each word around 50 times per month).

$$
\begin{aligned}
&\textbf{AMBLA:} \\
\text{AoA}_{ij} &= \{\text{Age}_i \mid y_{ij} = c\} \\
y_{ij} &= \text{Age}_i \cdot \text{Frequency}_j \cdot \text{Exposure}_{ij} \cdot \text{Cognateness}_j \\
\text{Frequency}_j &\sim \text{Poisson}(\lambda) \\
\text{Cognateness}_{j,j_{TE}} &= \text{Levenshtein}(j, j_{TE}) \\
\\
\text{Where:} & \\
i &: \text{ child} \\
j &: \text{ word-form} \\
j_{TE} &: \text{ Translation equivalent of word-form } j \\
\text{AoA}_{ij} &: \text{ Age-of-acquisition of word } j \text{ for child } i \\
c &: \text{ Threshold number of learning instances for word acquisition} \\
y_{ij} &: \text{ Learning instances with word } j \text{ accumulated by child } i \\
\\
\text{For simulations} &: c = 300,\ \lambda_j = 50
\end{aligned}
\tag{4.1}
$$

The third variable is the child's relative exposure to the language to which the word belongs to (Exposure_{ij}): children will accumulate learning instances with words from their higher-exposure language faster than with words from their lower-exposure language. This variable takes values from 0 (the child does not receive any exposure to this language) to 1 (the child only receives exposure to this language). The child's degree of exposure to all languages must sum up to one. Finally, the fourth variable is the amount of phonological similarity between the two TEs (Cognateness_j). This score ranges from 0 (no similarity) to 1 (identical cognates), and is calculated using the Levenshtein similarity, as in Section 2.2.3.3.

Figure 4.1 illustrates the outcomes of 50 simulations of the AMBLA model for the two TEs. Overall, the accumulation of learning instances is faster for the Catalan word-forms than for the Spanish forms, leading to an earlier age-of-acquisition for the former. This is an anticipated outcome, as the child is more likely to encounter Catalan word-forms in their speech input, compared to Spanish word-forms (again, assuming that lexical frequency is constant for the Catalan and the Spanish word-forms). This difference in age-of-acquisition between Catalan and Spanish word-forms is attenuated by their cognate status. The AMBLA model assumes a cross-talk between word-forms in both languages, in such way that learning instances for word-forms in one language may count as well for their TEs, as the result of their co-activation during speech comprehension. For instance, the Spanish word-form /ˈga.to/ benefits from the learning instances that its cognate translation /ˈgat/ receives (both word-forms share 0.75 Levenshtein similarity). The Spanish word-form /ˈpe.ro/ however, would benefit in a less degree from the learning instances accumulated by its non-cognate translation /ˈgos/, given their low phonological similarity (0.00). In the case of the cognate TE, the word-form in the language of lower exposure (Spanish) occurs at an earlier age than in the non-cognate TE, as the result of the language non-selective accumulation of learning instances across phonological links.

The simulations from AMBLA also reflect the asymmetric facilitation effect of cognateness on word acquisition. In the cognate TE, the word-form belonging to the language of lower exposure (Spanish) benefited from its cognate status more strongly than the Catalan word, which belonged to the language of higher exposure. These outcomes mirror the findings in Chapter 2, which provides converging evidence for the central mechanism of AMBLA: the cross-language accumulation of learning instances for cognate words. As previously explained, we hypothesis that the asymmetry in this effect is driven by the fact that word-forms from the higher-exposure language (which the child encounters more frequently) provide additional learning instances to their TEs than word-forms from the lower-exposure language (which the child encounters less frequently).

The simulations from AMBLA presented above correspond to a first inter-action in the formalisation of the model. Future work will be addressed at refining and expanding its current implementation. The ultimate goal is to make AMBLA a useful model for generating and testing quantitative predictions of word age-of-acquisition (Kachergis et al., 2022), while keeping a minimal structure and ensuring the interpretability of its parameters (see Magnuson et al., 2020 for a similar approach on a minimal model of spoken word recognition). More generally, we anticipate that a more principled formalisation of the inner workings of AMBLA may provide a stronger bridge between hypotheses about lexical development, and the statistical inference conducted on observations about word acquisition

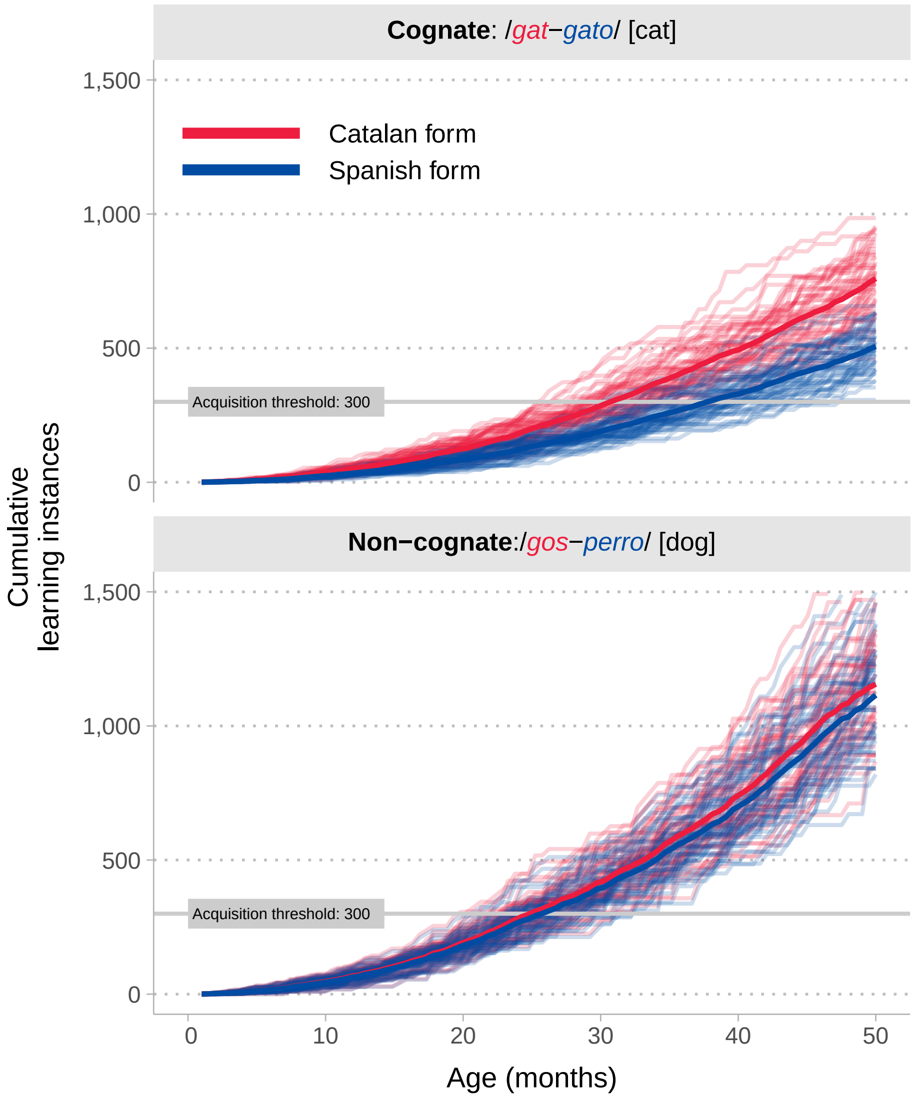

Figure 4.1: Simulations from AMBLA for the acquisition for two translation equivalents in Catalan and Spanish. Thinner lines represent 50 simulations for each word-form. Thicker lines indicate the mean of the simulations for the same word-form. Word-forms in Catalan are depicted in red. Word-forms in Spanish are depicture in blue. The X-axis indicates the age of participants in months. The Y-axis indicates the cumulative learning instances for each word-form. We indicate the threshold number of learning instances that a word must accumulate to be acquired with a horizontal grey line.

(Guest & Martin, 2021; Navarro, 2019; Wills et al., 2017).

4.3 Methodological contributions

A considerable part of the present dissertation has built on a database of vocabulary data collected from 2020 onwards. To gather this database, we designed and implemented an *ad hoc* questionnaire the Barcelona Vocabulary Questionnaire (BVQ) (Garcia-Castro et al., 2023). This questionnaire was filled in by a large sample of families of monolinguals and bilinguals aged 10 to 32 months, learning Catalan and Spanish. Collected data included comprehension and production estimates for individual words in Catalan and Spanish. Queries to the database can be performed through its associated R package `bvq` (https://gongcastro.github.io/bvq), which provides a sizable amount of acquisition reports, and may be used to address further research questions about bilingual lexical development. In addition, this questionnaire was developed open source software, and all the materials and code used in process are available at the GitHub repository (https://github.com/gongcastro/bvq).

Another contribution of the present dissertation is the modelling approach adopted throughout Chapter 2 and Chapter 3. We highlight two features of interest. First, we adopted a Bayesian approach to parameter estimation and statistical inference. This approach provides great advantages, compared to the more widespread frequentist approach. Among them, we highlight the possibility to incorporate previous knowledge about the distribution of parameters of interest in a model, providing a more stable and efficient computation of the posterior coefficients. This proved to be a valuable asset in the implementation of complex multilevel structures for the random effects of the models, which we describe below. Some participants contributed partial data sets, in which for particular combinations of levels of the predictors of interested, few observations were gathered, if any. In these cases, a frequentist approach would most likely have provided unstable inferences, if not computational complications (e.g., convergence issues during the estimation of parameters). Following a Bayesian approach, we specified a weakly informative prior for the parameters in our models, so that incoming observations would gradually update the shape of the distribution of the parameters until data collection concluded. At no point the parameters of the models provided unfeasible estimates, as the distribution of their parameters was constrained by theoretically grounded prior distributions.

In Chapter 2, caregivers of many —but not all of—participants provided answers about comprehension or production for the same words. Conversely, the same participant provided such responses to multiple—but not all of—words. To analyse this type of data sets, previous studies aggregated scores across items or participants, in order to avoid violations of the assumption of independence between the residuals of related observations (e.g., belonging to the same participant) (Bosch & Ramon-Casas, 2014; Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al., 2018). As a consequence, information at participant-level or item-level was not available in subsequent analyses. On the contrary, in this dissertation we incorporated the complex data collection design into the structure of our model in the form of IRT, in which participants and words were included as crossed random effects in the random effects structure of the model. Data analysis in Chapter 3 also benefited from this approach, given its complex data collection design, in which some participants were tested more than once. In this case, we included participants and testing sessions as nested random effects. In summary, the present dissertation benefited from a Bayesian approach to statistical inference that may be of interest for future research in language acquisition.

4.4 Limitations and future research

One of the main pitfalls encountered in this dissertation was the experimental caveats in Chapter 2. Our adaptation of the original implicit naming task by Mani and Plunkett (2010, 2011a) failed to reproduce the expected results. We introduced some adjustments to the structure of the trial, in order to maximise the probability of detecting cross-language priming effects. Such effects are short-lived and more difficult to detect than within language priming effects. For this reason, we removed the pre-naming phase of the trial, in which target and distractor pictures are presented prior to the auditory target label. This made the presentation of the prime picture and the target auditory label closer in time. We expected the immediacy of the presentation of both stimuli to increase of the size of the priming effect. Instead, this adjustment appeared to disrupt the lexical retrieval of the prime label, in such way that priming effects were not observed in any of the experimental conditions. This prevented us from drawing any conclusions about the presence of such effects in the initial lexicon from this experiment. Future research should address whether a longer inter-stimulus interval between the presentation of the prime and the target would lead to the observation of priming effects.

The present dissertation contributes several open questions. One of them is if the cognate facilitation effect reported in Chapter 2 is present in other populations of bilinguals, namely those learning more lexically dissimilar languages. As mentioned in the Discussion section of Chapter 2, Catalan and Spanish share many cognates. The large amount of cognates shared by Catalan and Spanish may increase infants' sensitivity to cross-linguistic phonological similarity during vocabulary acquisition leading to cognateness playing a more central role than in the case of infants who encounter fewer cognates in their linguistic input. For instance, infants learning English and Mandarin, two languages that share very few cognates, may not be able to exploit cross-language similarity to boost the acquisition of words in both languages during language exposure. The approach followed by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, Krott, Mills, et al. (2018; Floccia et al., 2020; see also Siow et al., 2023) of collecting data from infants learning a diverse pool of language pairs would be convenient for addressing this issue.

The evidence provided in Chapter 2 in favour of an earlier age-of-acquisition of cognates does not address the particular mechanisms infants may use to accumulate information about word-forms and their association to their corresponding referents. We used the term *learning instance* (Mollica & Piantadosi, 2017) to refer to exposures to a word in which infants *may* use to consolidate its lexical representation. Determining the specific condition under which a learning instance is effective (i.e., may lead to word learning) falls out of the scope of the present dissertation. We simply assume that some learning instances may be effective, and that the number of effective learning instance is a function of the total number of learning infants a child encounters on a daily basis. An experimental approach to word learning, in which the impact of cognateness is investigated, would provide valuable insights into the mechanisms behind the role of cross-linguistic similarity on word acquisition.

For instance, a recent study by R. K.-Y. Tsui et al. (2023) provides a potentially suitable paradigm to investigate the impact of cognateness on online word learning. The authors designed a word learning task in which they tested bilingual infants aged 3-to-5 years of age, learning French and English (in Montreal, Canada), and Spanish and English (in New Jersey, United States). In the learning phase, participants were trained to associate novel labels to novel objects. At test, participants were presented with pairs of objects encountered in the learning phase, and a label that corresponded to one of them. Participants were instructed to select the corresponding object in a touchscreen. Participants completed two blocks of training and test phases. In the training phase of one block, participants were presented with sentences labelling the novel objects in both languages in an interleaved fashion. For instance, in one trial they would be presented with a novel object, which would be labelled in English (e.g., *gasser* in English). In the next trial, they would be presented with the same object, which this time would be labelled in French (e.g., *donquete* in French, or *sasco* in Spanish). This condition simulated a *language mixing* environment (i.e., children are exposed to both languages in the same situations, encountering words from both languages interleaved in speech), to which a sizeable proportion of bilinguals are exposed (Byers-Heinlein, 2013). In the training phase of the other block, participants were presented with consecutive trials labelling the object in the same language, and then with consecutive trials labeling the object in the other language. This condition simulated a *one-language-at-a-time* environment. Overall, participants succeeded at learning the words in both conditions. This suggests that infants benefit equally from being exposed to labeling events in alternating languages in an interleaved fashion (a bilingual environment) and in an synchronous fashion (monolingual situations).

R. K.-Y. Tsui et al. (2023) used phonologically distinct novel labels across languages. By extending this paradigm it could be possible to investigate whether participants learning of the label-referent associations is facilitated by the degree of phonological between the TEs. If participants co-activate newly learned TEs in both languages, word learning should be facilitation more strongly by the repetition of phonologically similar TEs (i.e., cognates) than from the repetition of phonologically dissimilar TEs (i.e., non-cognates). Another variable of interest for such experimental paradigm could be the lexical similarity between the two languages being acquired. The two populations of bilinguals in R. K.-Y. Tsui et al. (2023), ones exposed to French and English, and the others to Spanish-English, were learning two languages belonging to two different typological families. At the lexical level both pairs of languages are relatively distant, compared to languages belonging to the same family, like Catalan and Spanish. By comparing how bilinguals process cognates in world learning contexts, depending on the overall lexical similarity of their languages (e.g., high in the case of Catalan and Spanish, low in the case of Euskera and Spanish), it could be possible to investigate how the linguistic input shapes the strategies followed by bilinguals during early lexical development. In summary, future steps may involve experimental paradigms to investigate the mechanisms involved in the cognate facilitation of word acquisition with more details, and with a finer control of the conditions in which participants are exposed to the word-forms.

4.5 Conclusions

The present dissertation provides insights into the developing bilingual lexicon. We provided evidence in favour of a mechanistic account of word acquisition, in which bilinguals exploit the language non-selectivity of their lexicon to facilitate the acquisition of cognate words. These findings have important consequences for the current understanding of bilingual vocabulary growth, and in particular, the mechanisms underlying the parallel trajectories of lexical acquisition of monolinguals and bilinguals.

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