

# The initial lexicon through the lens of bilingualism

Insights from lexical access and acquisition

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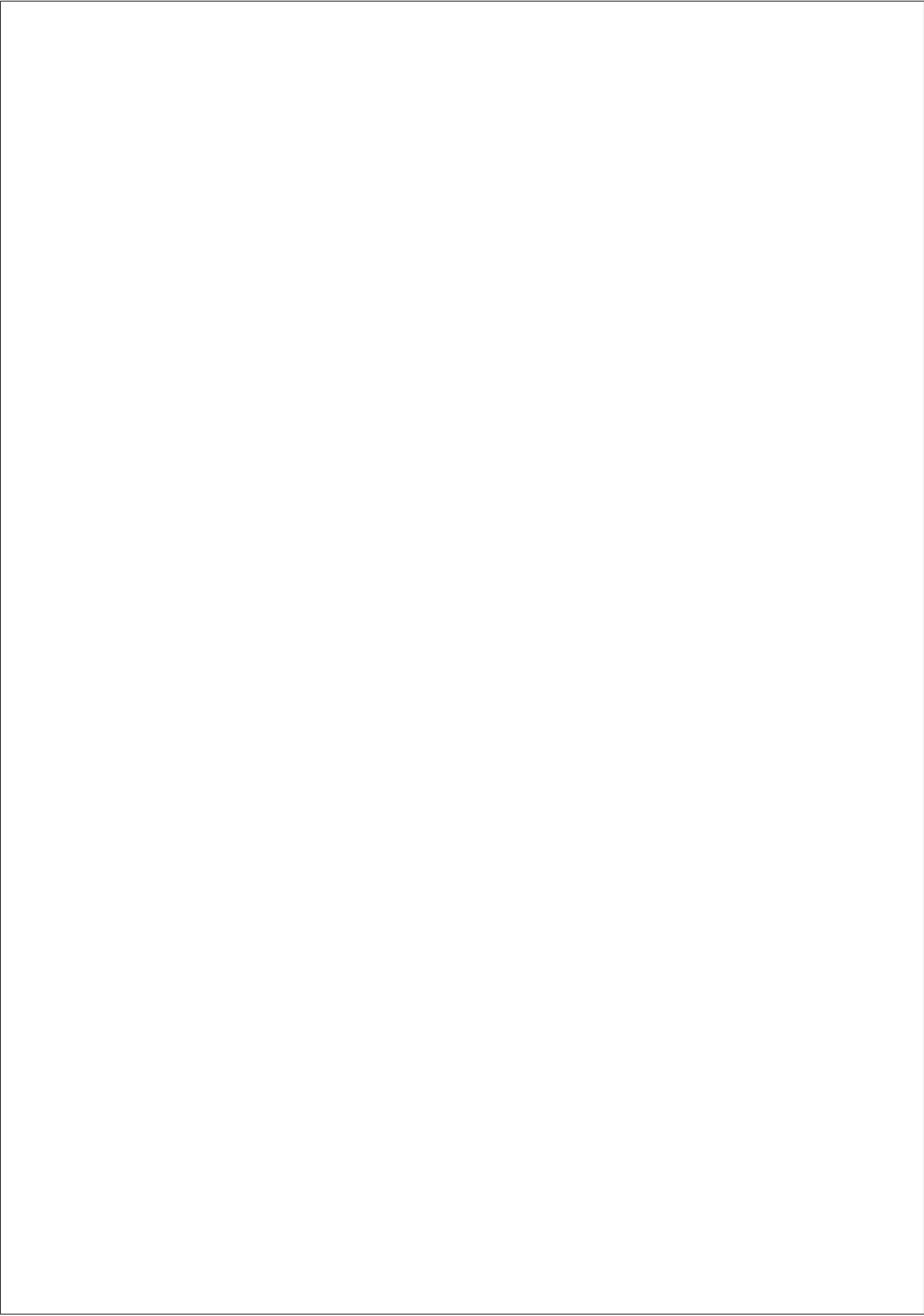
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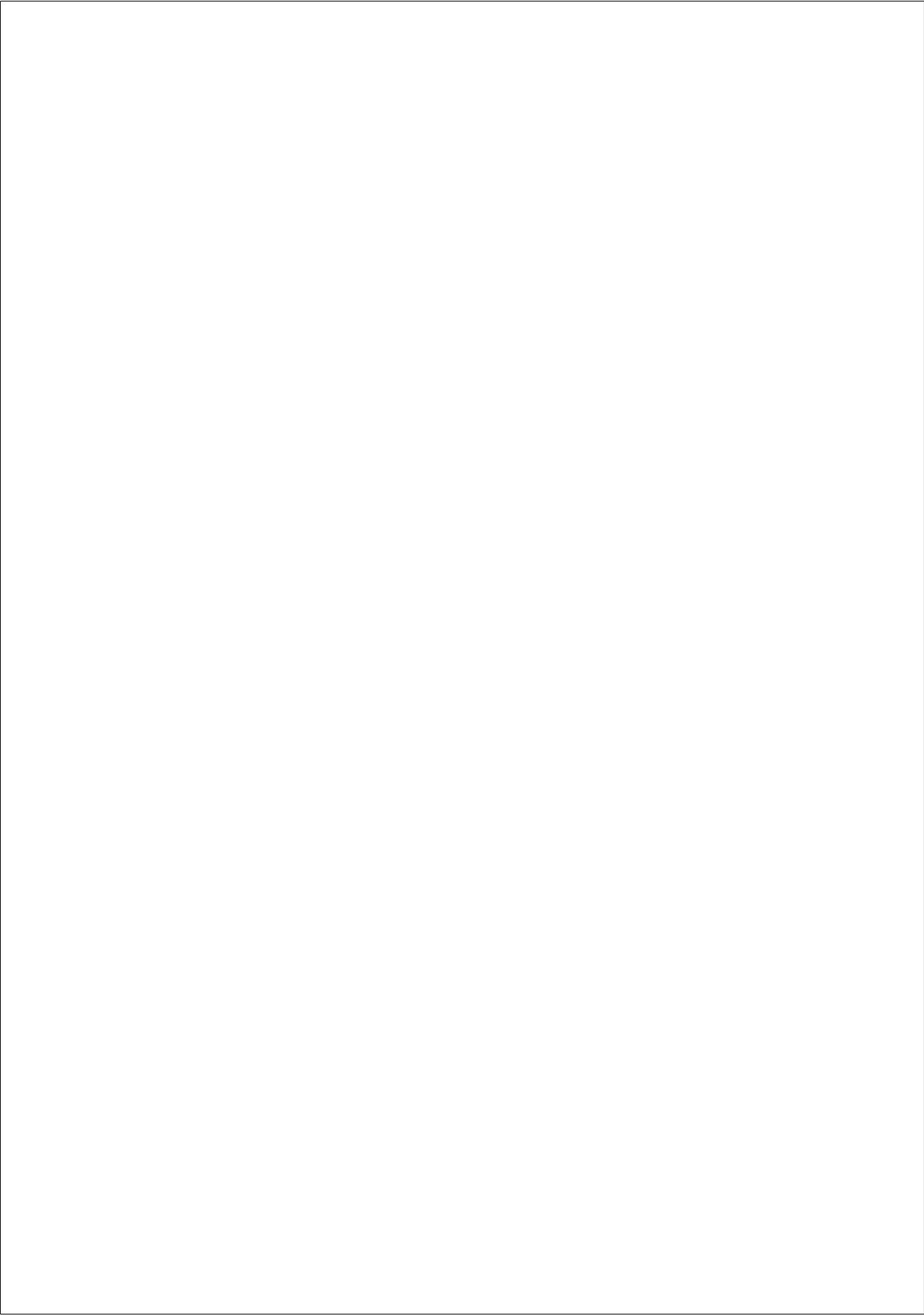
*A mamá, a papá, a Íñigo.*



## Acknowledgements

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## **Abstract**

Bilingual infants acquire words at a similar rate than monolinguals, 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 exposar-se a un entorn lingüístic més complex. En aquesta tesi, investiguem el paper de la cognasticitat (similitud en forma entre traduccions equivalents o TE) com a facilitador de l'expansió del lèxic. Hem modelat les trajectòries d'adquisició de les TE, revelant un efecte de facilitació de la cognasticitat en el llenguatge amb menor exposició. Expliquem aquests resultats mitjançant la hipòtesi no selectiva de l'accés lèxic, i vam posar a prova la suposició que els infants bilingües activin les TE en ambdues llengües simultàniament en situacions monolingües. Vam fer servir una tasca de reconeixement de paraules en la qual els participants van ser provats exclusivament en una de les seves llengües, mentre que les paraules primes es manipulaven de manera encoberta. Aquesta tesi aporta coneixements significatius sobre el paper de la no-selectivitat lingüística en el lèxic primerenc.



## Preface

Some things are more easily talked about than done. Talking about *talking*—an activity sometimes referred to as *Linguistics*—is however painfully difficult. The action of *talking* feels extremely easy for most humans. In fact, learning how to talk seems trivial for most infants. Language is the most complex communicative system known, yet very few people are surprised by the fact that infants pick it up so early in life, and so effortlessly. Developmentalists, however, are intrigued by early language acquisition and its implications on human cognition and evolution. How infants acquire the most complex communicative system known by humans in such a short time span is a question that has kept many folks out of unemployment, including myself for the last five years. This thesis explores a small area of language acquisition research: how infants learn a specific type of linguistic unit called *words*, and whether bilingualism—the simultaneous acquisition of two languages—impacts this process. Although some of the premises and claims expressed in the present work may apply

to infants acquiring language through modalities other than the auditory, the scope of the present work is the developmental trajectories of hearing, typically developing infants. For this reason, most examples and arguments concern the auditory modality, and refer to events that are specifically relevant to hearing infants, like *sound*, *hearing*, *auditory*. We invite the reader to consider the case of deaf infants as a natural extension of the point made, whenever possible. For instance, note that we adopt a broad definition of *phonology* in which a phonological system is present, with the only difference to oral languages that the forms of the linguistic units is motor-visual.

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# **1 Introduction**



One of the main developmental milestones in language acquisition is the ability to make sense from the speech stream.

, and retrieving their meaning. Being able to recognise familiar word-forms and retrieve their meanings The present thesis delves into the interface between concepts and speech sounds, known as the mental *lexicon*, and how it emerges during the first years of life. We consider the case of simultaneous bilinguals as a particular case of language acquisition that requires infants to deploy some additional strategies in their learning trajectories. 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 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 thesis.

## **1.1 The foundations of a lexicon**

### **1.1.1 From sounds to word-forms**

Infants' earliest demonstrations of language familiarity trace back to their last weeks of pre-natal life. Hearing infants 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 their carrier is talking (DeCasper & Fifer, 1980; Kisilevsky et al., 2009; Voegtline et al., 2013), and can identify familiar melodies uttered by their carriers (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 some other 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 et al., 1994; Kuhl, 1991; Kuhl et al., 2006; Segal et al., 2016; Werker & Tees, 1983, 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<sup>1</sup>. This task is not trivial. 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,

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<sup>1</sup>Attempting to provide a clear definition of *word* goes beyond the aims of the present thesis. 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*."

2005b; Jusczyk et al., 1994), phrase- and sentence-level 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 & Boysson-Bardies, 1996; 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, 2005a; 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.

### **1.1.2 Early word comprehension**

Infants start building a lexicon early in age, as infants associate phonological representations of word-forms to referents and events<sup>2</sup>. Evidence

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<sup>2</sup>Although the role of the grammar in the early lexicon falls outside of the scope of the present thesis, we acknowledge that grammatical information is incorporated in the lexicon, together with concepts and word-forms (Caramazza, 1997; Krauska & Lau,

from inter-modal paradigms of word recognition (Delle Luche et al., 2015; Hirsh-Pasek & Golinkoff, 1996) have show that, by six months of age, infants are already forming their first lexical representations. For instance, Bergelson and Swingley (2012a, 2015) presented pairs of familiar pictures to infants at different age points, from six to twenty months. In each trial, their caregiver named one of the pictures, participants' looking preference for the named picture was measure, and 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 month 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, 1999a, 2012).

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2023), but we do not adhere to any particular account of way in which grammatical information may be encoded in the lexicon.

### 1.1.3 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 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 the CDI 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 much 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).

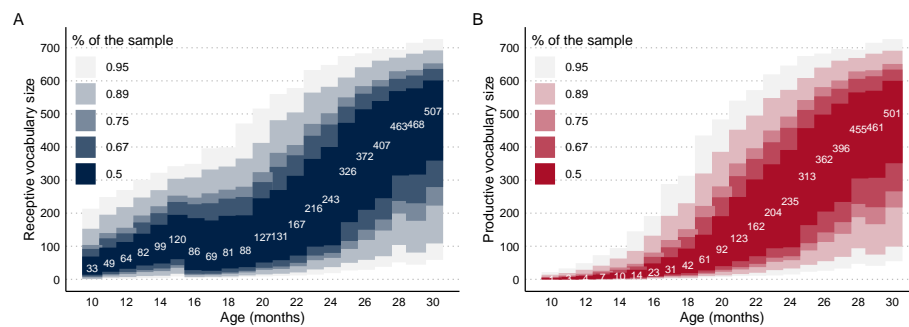


Figure 1.1: Wordbank norms for receptive (A) and productive (B) vocabulary size in monolingual children. Vocabulary sizes are expressed as the number of words that caregivers reported to be acquired by their child, either as *Understands* (receptive vocabulary) or *Understands and Says* (productive vocabulary).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

## 1.1.4 The structure of the early lexicon

### 1.1.4.1 Dynamics of 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 to 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: conceptual, lexical, and phonological (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 activations are activated across the three levels is determined by bottom-up and top-down sources of information. To illustrate this, we will focus on the dynamics of word comprehension (see Figure 1.2).

Spoken word recognition starts with the acoustic-phonetic processing of the speech signal. Phonological segments (e.g., phonemes, syllables) in the repertoire of the listener are activated according to how well they match the phonetic features and co-articulatory information provided by the speech stream. Activation spreads to lexical representations whose associated phonological contain the activated segments. The set of lexical

candidates then is modulated top-down information provided by 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 concept is activated for comprehension. This sequence of events occurs in a *cascaded* fashion. As the recognition system accumulates information about the unfolding acoustic signal matching word-form representations are accessed—even if they ultimately are not selected—and in turn activate their associated semantic representations. As, activation spreads across levels of representation, through shared phonological (Grosjean, 1980; Luce et al., 1990; e.g., W. D. Marslen-Wilson, 1987; W. D. Marslen-Wilson & Welsh, 1978; McClelland & Elman, 1986) or semantic features (Collins & Loftus, 1975; Neely, 1977) the dynamics of word comprehension and production are impacted.

A clear example of cascaded activation at the phonological and semantic level was provided by Allopenna et al. (1998). The authors designed a word-recognition task in which participants were presented, in each trial, with four objects in the screen. Participants would then listen to a command like “Pick up the beaker; 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 did so at an earlier time window than those sharing phonological offset. This time course of distractor fixations suggests that the auditory presentation of the target label activated not only its (subsequently selected) phonological form in participants' lexicon, but also that of phonologically related word-forms, leading to competition for selection between the word forms.

#### **1.1.4.2 Phonological and semantic priming**

Priming paradigms of word recognition have provided evidence of this cascaded activation in the developing lexicon. The rationale behind these paradigms is generally as follows: at the beginning of each trial, infants are presented with a prime word or picture that will activate its associated lexical representation. In a second part of the trial, a target word is presented, together with a pair of pictures. One of the pictures represents the referent of the target word. Participants' looking preference for the target picture—compared to the other (distractor) picture—is interpreted as evidence of target word recognition. By manipulating the semantic or phonological relationship between the prime and the target words, it is possible to investigate how word recognition is affected by the previous

activation of related lexical representations.

Priming paradigms of word recognition have provided a strong body of evidence for the existence of phonological and semantic links between early lexical representations between 18 and 21 months of age. Arias-Trejo & Plunkett (2009) found that infants' spoken word recognition (e.g., *dot*) 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. In the same line, Styles & Plunkett (2009) reported semantic priming in 24 month-old participants but not in 18 month-old participants. Other studies have provided electrophysiological evidence of semantic priming at earlier ages (Friedrich & Friederici, 2005a; e.g., Rämä et al., 2013). More recent studies have provided evidence for the emergence of such semantic links from 24 months onwards, even in the absence of visual referents during the experimental task (Willits et al., 2013). Overall, semantic associations in the initial lexicon are in place before infants' second birthday.

Phonological priming effects have also been reported to emerge around the same ages. Mani & Plunkett (2010) and Mani & Plunkett (2011a) created 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, English monolingual infants showed different target looking preference patterns after phonologically related prime pictures, compared to after phonologically unrelated primes. This suggests that infants implicitly named prime pictures—despite such pictures having been presented in silence—and that the phonology of the resulting labels interacted with subsequent target. The direction of the effect was different in both age groups. In 18 months, infants showed stronger target preferences after being previously presented with a phonologically related prime. On the other hand, 21 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 result of the increased 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. A recent study by Avila-Varela et al. (2021) provided converging evidence from German monolinguals, in which larger interference effects were found in participants with larger vocabulary sizes, even after controlling for their age. Chow, Aimola Davies, et al. (2017) provided further evidence of the emergence of semantic *and* phonological links, associated to lexical growth. The authors adapted the Visual World Paradigm from Huettig & McQueen (2007) to explore 24- to 30-month-old toddlers' visual fixation patterns during a word recognition when presented with phonological and semantic distractors. In each trial, the authors presented participants with four semantically and phonologically pictures. Four seconds after pictures onset, a word-form was auditorily presented. The word did not refer to any of the pictures displayed on the screen, but was phonologically related to one of them (both labels shared phonological onset), and semantically related to another one of the pictures (both referents belonged to the same taxonomic category. For instance, participants might be 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 authors registered participants fixations to the phonological and semantic distractors, and found evidence of 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 effects were stronger in participants with larger vocabulary sizes.

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 Characterising bilingualism**

In lay terms, *bilingualism* can be defined as the regular use of two or more languages. For bilingualism research, this definition is no more than vague. Individuals may be labelled as *bilingual* for very different reasons. For instance, if a child is raised in a household where two languages co-exist, this child is conventionally considered bilingual. So would be an adult learning a second language later in age through formal instruction. The *bilingual* label suits both of situations, despite their radically different language experiences. The former case describes a *simultaneous bilingual*, who learns two languages in parallel during the first stages of their development. The latter case describes a *sequential bilingual*, whose is already native in one language at the time they start learning a second. The *simultaneous bilingual* will achieve native-level proficiency in both



languages, equivalent to that of their monolingual counterparts. In contrast, the *sequential bilingual* will face severe limitations in their learning journey, as their prior language experience will constrain their language learning abilities (see Costa & Sebastian-Galles, 2014 for review). In summary, characterising bilingualism using one dimension or other (e.g., age of acquisition, second language proficiency) has critical methodological consequences for bilingualism research (Grosjean, 1997).

Since the present dissertation concerns simultaneous bilingualism in infancy, we identify bilingualism with dual language exposure. This definition is useful to describe the linguistic experience of bilingual infants who participate in linguistic interactions almost exclusively as listeners. 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). For monolinguals, this is relatively easy to measure, since most people, if not all, talk to the infant in the same language. In bilinguals, this linguistic input is divided into two languages, which may be spoken by the same or 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 & Sebastian-Galles, 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 judgements of caregivers, there is strong 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 in monolinguals to 50% in *balanced bilinguals*, with intermediate scores representing more *unbalanced bilinguals* (e.g., 25%). 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 universal threshold from which a child is considered bilingual, most of such studies considered a child as bilingual if the child is exposed to a second language at least 20% of the time (Byers-Heinlein, 2015; Byers-Heinlein, Tsui, Bergmann, Black, Brown, Carbajal, Durrant, et al., 2021; Rocha-Hidalgo & Barr, 2023a) (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.

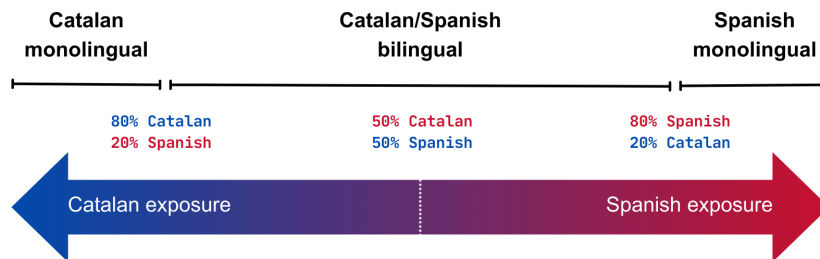


Figure 1.3: Bilingualism.

### 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, this means that they receive less exposure in each of their languages than monolinguals do. Second, bilinguals need to learn two codes, which might partially overlap: two phonologies, two grammatical systems, and two lexicons. Third, the referential context in which bilinguals build a lexicon is also more complex. On the one hand, bilinguals frequently learn at least two labels for the same referent, one for each language. On the other hand, 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.

While these increased cognitive demands do not keep bilinguals from reaching their language acquisition milestones at similar ages as monolinguals, it modulates the trajectories followed by bilinguals (see Sebastian-Galles & Santolin, 2020a for review). For instance, bilingual infants show evidence of language discrimination abilities slightly later than monolinguals (Bosch & Sebastian-Galles, 2001; Bosch & Sebastián-Gallés, 1997), and possibly do so relying on different strategies (e.g., Byers-Heinlein et al., 2010; Nacar Garcia et al., 2018; Sebastián-Gallés et al., 2012; Weikum et al., 2007). Bilinguals also tune their perceptual abilities to the phoneme repertoire of their native languages at similar ages as monolinguals, although their discrimination trajectories are different from monolinguals' for some phonemic contrasts (Albareda-Castellot et al., 2011; Bosch & Sebastián-Gallés, 2003; Burns et al., 2007; Sundara et al., 2006, 2008). Word-form segmentation abilities have been observed at similar ages in both groups (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 their 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., 2013a, 2017). These changes are dependent on the relative amount of input that the bilingual infant receives from each language. For instance, bilinguals acquire words faster, and become more efficient at spoke 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, et al., 2018; Hoff, 2003; Marchman et al., 2010; Shneidman et al., 2013; Thordardottir, 2011). Overall, the monolingual and the bilingual lexicons mature at a similar rate, but do they follow identical trajectories? Previous studies suggest this is not the case.

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 the MCDI, and families of English-Spanish bilinguals filled the MCDI and its Spanish adaptation, the *Inventario del Desarrollo de Habilidades Comunicativas* (Jackson-Maldonado et al., 1993). When compared in their English vocabulary size, monolinguals were reported to produce a higher number of

words, compared to bilinguals. English vocabulary size in bilinguals was associated with infants' amount of exposure to English: English-dominant bilinguals, raised in predominantly English speaking homes, showed the next largest English vocabulary size, compared to balanced or Spanish dominant bilinguals. Overall, English vocabulary size was showed to be a function of infants' exposure to English at home, with infants raised exclusively in English showed the largest English vocabulary sizes, followed by English-dominant bilinguals, balanced, and Spanish-dominant bilinguals, in that order. When the authors examined Spanish vocabulary sizes, they found a similar graded effect of Spanish exposed, in which Spanish-dominant bilinguals had larger Spanish vocabulary sizes than balanced in English-dominant bilinguals.

Results from Hoff et al. (2012) suggest that the relatively reduce amount of input that bilingual receive has a toll in their vocabulary growth in each language, when compared to monolingual infants. But single-language vocabulary size comparisons are an uneven ground in which to contrast the lexicon of monolingual and bilingual and bilingual children. When only one language is evaluated, many words in the other language that bilinguals may know are not counted (Bedore et al., 2005). When both languages are summed together, the size of the lexicons of bilinguals are, overall, equivalent to those of monolinguals, or even larger (Bosch & Ramon-Casas, 2014; Byers-Heinlein et al., 2023a; Core et al., 2013; Pearson et al., 1993; Pearson & Fernández, 1994; Poulin-Dubois et al., 2013a).

For instance, when Hoff et al. (2012) summed together the English and Spanish vocabulary sizes of bilingual participants into a measure of total vocabulary size, the trajectories of vocabulary growth of monolinguals and bilinguals were equivalent. This suggests that, despite acquiring words at a slower rate than monolinguals in their corresponding languages, bilinguals' lexicons have equivalent sizes to those of monolinguals when words in both languages are taken into consideration.

Data collected in our group provide evidence in this line, suggesting that when both languages are taken into account bilinguals may know the same—if not more—more words than monolinguals (see Figure 1.4). In line with Hoff et al. (2012)'s results, we found a graded effect of quantitative language exposure on vocabulary size. As expected, Catalan monolinguals and Catalan-dominant bilinguals show larger Catalan vocabulary sizes across ages in both comprehension and production. Conversely, Spanish monolinguals and Spanish-dominant bilinguals showed larger Spanish vocabulary sizes. Overall, most monolinguals showed non-zero vocabulary sizes in a second language, which is to be expected from the fact that few of them received no-zero exposure to a second language. More interestingly, total vocabulary sizes are higher in both Catalan-dominant and Spanish-dominant bilinguals, compared to Catalan and Spanish monolinguals. This contrasts with Hoff et al. (2012)'s results, and suggests that Catalan-Spanish bilinguals actually know more words than their monolingual peers across ages.

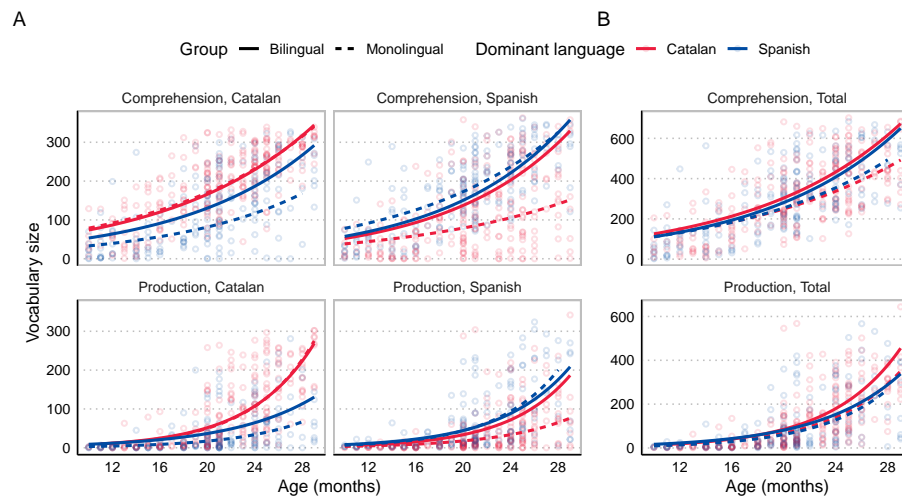


Figure 1.4: Receptive and productive vocabulary size of monolinguals and bilinguals in Barcelona. We used the Barcelona Vocabulary Questionnaire (Garcia-Castro, Ávila-Varela, et al., 2023), an *ad hoc* extension of the CDI to Catalan and Spanish, to collect vocabulary data from 173 monolinguals (exposed to at least 80% of the time to Catalan or Spanish) and 213 bilinguals (exposed to less than 80% of the time to Catalan or Spanish). Participants provided a total of 437 administrations of the questionnaire. A) Language-specific vocabulary sizes in Catalan and Spanish B) Total vocabulary size for comprehension and production, resulting from the sum of Catalan and Spanish vocabulary sizes.



### 1.2.3 Composition of the early bilingual lexicon

The mechanisms that allow bilinguals to keep up with monolinguals in their lexical development, despite facing a more complex linguistic environment, are elusive. The analysis of the composition of the initial bilingual lexicon has provided some insights. Early accounts of bilingual word acquisition predicted that bilinguals might initially avoid learning cross-linguistic synonyms (henceforth *translation equivalents* or TEs) (Volterra & Taeschner, 1978), in a similar way monolinguals do with within-language synonyms (e.g., Markman et al., 2003). It was later shown that TEs are present in bilinguals' lexicons since early ages (Poulin-Dubois et al., 2013a, 2017; R. K.-Y. Tsui et al., 2022). In fact, TEs might play a central role in the growth of the bilingual lexicon. For instance, Bosch & Ramon-Casas (2014) inspected the contents of the vocabularies of a sample of 18-month-old bilinguals learning Catalan and Spanish, who showed equivalent total vocabulary sizes to their monolingual counterparts. The authors found a large number of TEs. Most of the words in infants' vocabulary in one language had also been acquired in the other. This suggests a preferential acquisition of translation pairs during early lexical acquisition in bilinguals.

In line with this claim, Core et al. (2013) computed the *conceptual vocabulary size* of English-Spanish bilinguals, a measure that indicates the

number of concepts a child has lexicalised. This measure is calculated by counting the number of TEs for which a bilingual child has acquired at least one word in one of the languages. Core et al. (2013) and Byers-Heinlein et al. (2023a) found significantly lower conceptual vocabulary sizes in bilinguals, compared to monolinguals. In line with previous studies, total vocabulary sizes in both groups were equivalent. This suggests that bilingual participants in their sample preferentially acquired TEs, which increased the number of acquired words in total, at the cost of acquiring words for a smaller number of concepts. Modelling vocabulary data from English-Spanish bilinguals, Bilson et al. (2015) provided converging evidence of this semantic facilitation across languages. Models in which TEs were preferentially acquired—the acquisition of words for which the model had already acquired a translation was prioritised—fitted better the observer trajectories of word acquisition in bilinguals. Overall, these findings point to a cross-language facilitation during lexical growth, in which the acquisition of words in one language scaffold the acquisition of words in the other language.

Not all bilingual populations have shown the same 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.

#### **1.2.4 Language distance and vocabulary growth**

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 (i.e., form-similar translation equivalents) 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, 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.

Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, et al. (2018) conducted an impressive study in 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 being 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, these results suggest that infants might 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 instance, 98% of the translation equivalents acquired by bilingual participants in Bosch & Ramon-Casas (2014) were form-identical, indicating that the preferential acquisition of translation equivalents might be modulated by the lexical similarity of both languages. 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 1.5 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, 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 an additional language, like those in Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, 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).

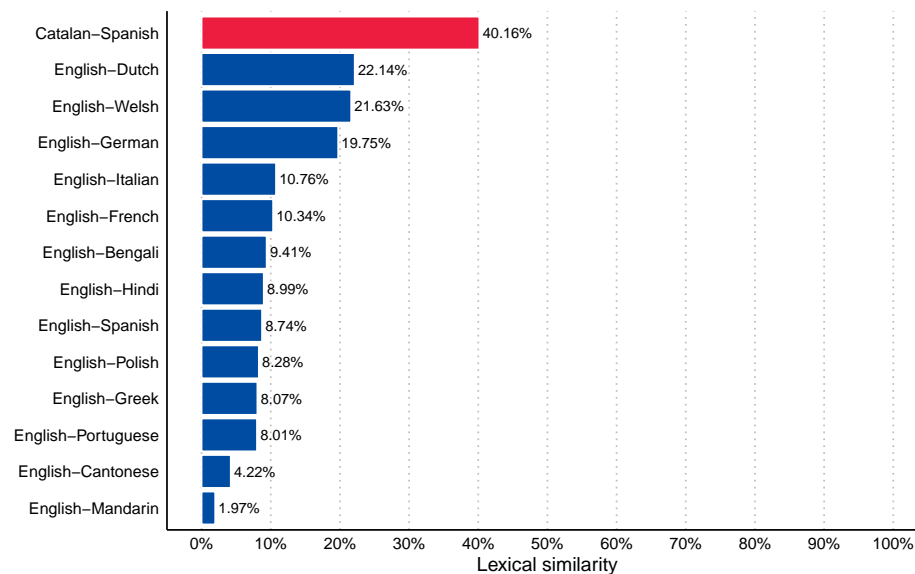


Figure 1.5: Lexical similarity between Catalan and Spanish, and between English and each of the additional languages in Floccia et al. (2018). We first obtained the broad phonological transcriptions of the words included in the Catalan and Spanish vocabulary checklists of the BVQ. Catalan words were 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.

The facilitation effect of lexical similarity on vocabulary growth reported by Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, 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 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.

### **1.2.5 The language non-selective hypothesis of lexical access**

To explain the facilitation effect of lexical similarity on vocabulary growth, Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, 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.

For instance, Marian & Spivey (1999) presented Russian-English bilinguals with a series of trials that started with an auditory instruction like “*Poloji marku nje krestika*” [“Put the stamp below the cross”]. The instruction would be present in Russian (dominant language for most participants). The target object (*marku* [*stamp*], in this case) would be present in the screen, together with an object whose English label shared phonological onset with the target label (e.g., *mark*), and two unrelated distractors whose labels in Russian and English did not share phonological relationship with the target label. Converging 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 1.6 illustrates this sequence of events.

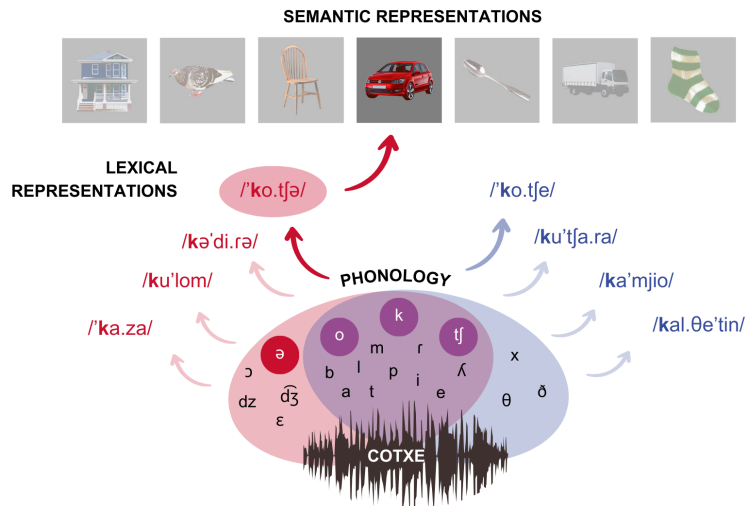


Figure 1.6: Lexical access and selection in the language-non selective bilingual lexicon.

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 to *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 top-down cascaded activation spreading across lexical representations in both languages. This is exemplified by the case of cognates. Cognates hold a privileged position in the language-non selective account of the bilingual lexicon, embodying the case of two lexical representations that belong to different languages, while sharing a common semantic representation (or at least, equivalent

semantic representations), and a fair amount of form-overlap. Through the study of cognate processing, previous studies have provided strong evidence of parallel activation in exclusively monolingual tasks. In Costa et al. (2000), Catalan-Spanish monolingual and bilingual adults 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*)—whereas in the other half of the trials labels were non-cognates (*taula-mesa*, translations of *table*). Bilingual named cognate pictures faster than non-cognate pictures, even after adjusting for the lexical frequency of the items. Spanish monolinguals did not show this effect, as they were unfamiliar with the phonological form of the words in Catalan. These results suggested that, for the bilinguals, Spanish phonology was activated during cognate trials, facilitating the production of the Catalan word-forms.

In adults, the available evidence in favour of language non-selectivity in the bilingual lexicon is abundant across modalities (Giezen & Emmorey, 2016; Gimeno-Martínez et al., 2021a; Van Heuven et al., 1998), and spans multiple 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). Modelling efforts have successfully implemented formal accounts of the bilinguals lexicon by incorporating cross-language interactions (A. Dijkstra & Van Heuven, 2002; T. Dijkstra et al., 2019; e.g., Kroll et al., 2010; Kroll & Stewart, 1994). In summary, there is overall consensus

around the fact that bilinguals co-activate both languages during word comprehension and production.

### **1.2.6 Parallel activation in the developing lexicon**

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., 2013a, 2017; Singh, 2014; Von Holzen et al., 2019a; Von Holzen & Mani, 2012a). Priming paradigms of word recognition tasks have been instrumental in this line of research. Using one of such paradigms, Von Holzen & Mani (2012a) 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; Jarda & Byers-Heinlein, 2019; Singh, 2014; e.g., Von Holzen & Mani, 2012a) present a critical methodological pitfall. In these tasks, participants are forced into a bilingual context, in which the overall degree of activation of lexical representations in both languages is 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 considerable proportion of bilingual children, speech input in each language takes place at separate times. 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, et al. (2018) to explain the cognateness facilitation effect relies on the language non-selectivity of the early lexicon. But experimental evidence

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.

### **1.3 The present thesis**

The aim of this thesis 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., 2022a; McMurray, 2007; Mollica & Piantadosi, 2017a). 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, 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 contrasted this model against vocabulary data from bilinguals, collected using an *ad hoc* online questionnaire 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, 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 be result of an overall stronger activation of both languages induced by the experimental task, and not because of regular cascaded activation across languages. In Chapter 3, we capitalise on the implicit naming paradigm by Mani and Plunkett (2010, 2011a) to test parallel activation in an exclusively monolingual task. This paradigm consists on a prime word recognition task in which primes are presented in the form of pictures presented in silence. Previous studies have provided strong evidence suggesting that infants at 18 months and older lexicalise name-known pictures presented in silence (Duta et al., 2012; Mani & Plunkett, 2010, 2011a; Styles et al., 2015). In particular, Mani and Plunkett 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 to the prime image, we tested parallel activation in bilingual toddlers while avoiding

the presentation of words in both languages.

## **2 Chapter 2: Cognate beginnings to bilingual lexical acquisition**

### **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, 2012b, 2015; Tincoff & Jusczyk, 1999b), 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, 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 Man-

darin. Blom et al. (2020b), 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 pro-

portion 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, 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., 2021b; 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 & Hell, 2012; Poulin-Dubois et al., 2013b; Von Holzen et al., 2019b; Von Holzen & Mani, 2012b). 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 theoretical 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 /'gat/–/'ga.to/ [cat], which are phonologically very similar. When the child listens to /'gat/, they will strongly co-activate /'ga.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 /'gos/–/'pe.ro/ [dog] would be different. Given the low phonological similarity between both word-forms, an exposure to\* 'gos will result in a weak activation of /'pe.ro/ leading to such exposure counting as a learning instance for /'gos/ (which the child was exposed to), but not for /'pe.ro/. While /'gat/–/'ga.to/ will benefit from phonological co-activation, /'gos–'pe.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 /'gat/ more frequently than the Spanish form /'ga.to/. Through parallel activation, /'gat/ will activate /'ga.to/ more often than vice versa. Ultimately, /'ga.to/ will benefit more strongly from its cognate status than /'gat/, as it receives additional learning instances from its translation equivalent more often than /'gat/.

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, Ávila-Varela, 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

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	radio, telephone
Food and drink	29	26	23	27	applesauce, watermelon
Animals	26	23	19	25	penguin, rat
Outside	14	13	13	15	pool, store
Body parts	14	12	11	11	eyebrow, tooth
Toys	11	11	12	13	painting, rake (object)
Clothes	12	12	10	10	belt, skirt
Vehicles	9	10	11	10	ambulance, subway
Colours	6	6	6	6	red, green
People	7	4	6	6	cousin, aunt
Furniture and rooms	4	4	4	4	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	-

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.

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

Table 2.2: Participant sample size by age and degree of exposure to Catalan.

Catalan exposure	Age (months)					
	[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
N	43	64	132	125	63	9

For participants exposed to Catalan and Spanish exclusively, the proportion of Catalan exposure shown in the table is complementary to the degree of exposure to Spanish. For participants exposed to a third language this proportion is not complementary unless one adds the degree of exposure to the third language, which never exceeded 10%. Participants with 100%, 0%, and 50% Catalan exposure would traditionally be classified as Catalan monolingual, Spanish monolingual, and Catalan-Spanish bilingual, respectively.

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%).

### **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],  $n = 48$ ), 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 ( $n = 33$ ). This resulted in a final list of 604 items, corresponding to 302 Catalan words and their 302 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 ( $Min =$

106,  $Max = 872$ ) 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 the Model predictors section. 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 Appendix A for a detailed description of the model and its diagnostics.



### **Response ( $k$ ) to word $i$ by participant $j$**

$$\text{Response}_{ij} \sim \text{Cumulative logit}(\theta_{k_{ij}})$$

where  $k \in \{\text{No} \rightarrow \text{Understands}, \text{Understands} \rightarrow \text{Understands and Says}\}$

### **Distribution parameters**

$$\begin{aligned} \theta_{k_{ij}} = & (\beta_{0_k} + u_{0_{i_k}} + w_{0_{j_k}}) + (\beta_1 + u_{1_i} + w_{1_j}) \cdot \text{Age}_i + \\ & (\beta_2 + u_{2_i} + w_{2_j}) \cdot \text{Length}_{ij} + (\beta_3 + u_{3_i} + w_{3_j}) \cdot \text{Exposure}_{ij} + \\ & (\beta_4 + u_{4_i}) \cdot \text{Cognateness}_{ij} + (\beta_5 + u_{5_i} + w_{3_j}) \cdot (\text{Age}_i \times \text{Exposure}_{ij}) + \\ & (\beta_6 + u_{6_i}) \cdot (\text{Age}_i \times \text{Cognateness}_{ij}) + \\ & (\beta_7 + u_{7_i}) \cdot (\text{Exposure}_{ij} \times \text{Cognateness}_{ij}) \\ & (\beta_8 + u_{8_i}) \cdot (\text{Age}_i \times \text{Exposure}_{ij} \times \text{Cognateness}_{ij}) \end{aligned}$$

where:

$\beta_{1-8}$ : fixed effects

$u_{1-8_i}$ : participant-level random effects

$w_{1-3_j}$ : TE-level random effects

### **Prior**

$$\beta_{0_k} \sim \mathcal{N}(-0.25, 0.5); \beta_{1-5} \sim \mathcal{N}(0, 1)$$

$$\sigma_{u_{0-8}, w_{0-3}} \sim \mathcal{N}_+(1, 0.25); \rho_{u_{0-8}, w_{0-3}} \sim \text{LKJcorr}(2)$$

where:

$\sigma_{u_{0-8}, w_{0-3}}$ : are the standard deviations of  $u$  and  $w$

$\rho_{u_{0-8}, w_{0-3}}$  are the correlations between random effects in  $u$  and  $w$

(2.1)

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.

### **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., 2019a). 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., 2014a; Zipf, 1949). 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. For each translation equivalent, we used the `stringdist` (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., /'taw.lə/–/'me.sa/, table), and one indicates that the two word-forms are identical (e.g., /'mar/–/'mar/, sea) (Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, 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.\*

#### **2.2.3.4 Statistical inference**

We assessed the practical relevance of the estimated regression coefficients of the model following 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 Appendix A for considerations about statistical power and sample size.

## 2.3 Results

The model posterior showed adequate chain convergence diagnostics and posterior predictive checks (see Appendix A). 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<sup>1</sup>. The resulting values correspond to the maximum difference in probability of acquisition (Comprehension or Comprehension and Production) that corresponds to a one standard deviation change in each predictor.

We now present our confirmatory 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

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<sup>1</sup>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  $j$ .

Table 2.3: Posterior distribution of regression coefficients. Median: 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.

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

$\beta$ : 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 posterior probability that the true value of the coefficient is equivalent to zero.

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.

The coefficient of Age showed the strongest association with the probability of acquisition ( $\beta = 0.405$ , 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 ( $\beta = 0.234$ , 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 ( $\beta = -0.062$ , 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 ( $\beta = 0.073$ , 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 ( $\beta = 0.058$ , 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 ( $\beta = -0.057$ , 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).

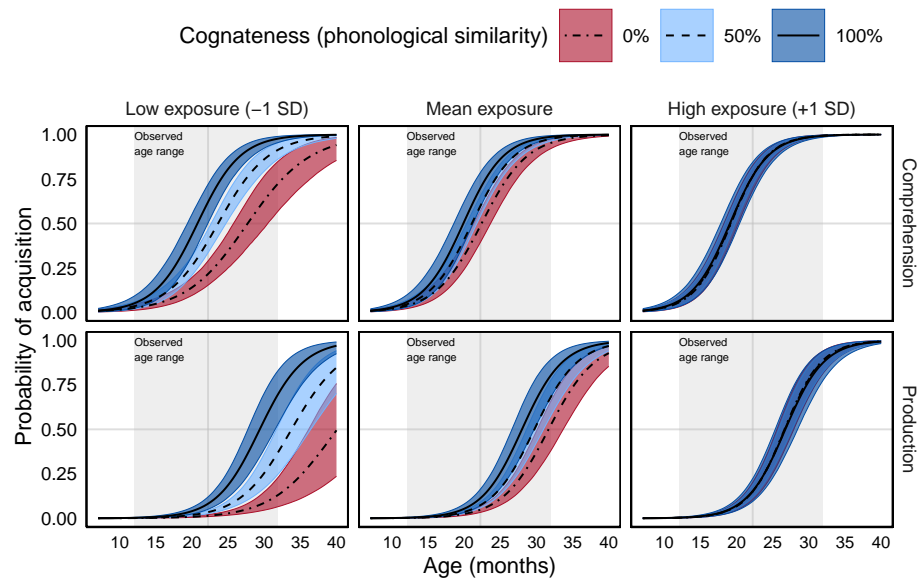


Figure 2.1: Posterior marginal effects. Lines and error bands correspond to the mean and 95% credible interval of the posterior-predicted means. Different shades of grey indicate different levels of cognateness (phonological similarity). Predictions are presented separately for different degrees of word-form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

An additional analysis including lexical frequency and language exposure as separate predictors (instead of the composite Exposure measure) showed equivalent results (see Appendix B). To rule out the possibility that cognate-



ness 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 Appendix C).

## **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., 2022b 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, 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., 2022b; Mollica & Piantadosi, 2017b), 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 monolingual 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., 2019b; but see Jardak & Byers-Heinlein, 2019). On 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+ (T. Dijkstra & Van Heuven, 2013), BLINCS (Shook & Marian, 2013), or Multilink (T. 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, 2023a). 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 /'gat/ and /'ga.to/ in the same situations), it is possible that infants classify both 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., 2009b, 2017; Ramon-Casas & Bosch, 2010; Swingley, 2005b; 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, 2020b). 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.

### **3 Developmental trajectories of bilingual word recognition**

#### **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, 2012a, 2015; Hallé & Boysson-Bardies, 1994; Parise & Csibra, 2012; Tincoff & Jusczyk, 1999a; 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., 2023b; De Houwer et al., 2014; Hoff et al., 2012; Legacy et al., 2018; Pearson & Fernández, 1994; 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., 2020a; Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith, et al., 2018; Gampe et al., 2021). Floccia, Sambrook, Delle Luche, Kwok, Goslin, White, Cattani, Sullivan, Abbot-Smith,

et al. (2018) reported larger vocabulary sizes in bilingual toddlers learning 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 phonological 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 were 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; Garcia-Castro, Avila-Varela, et al., 2023; Mitchell et al., 2022; Schelletter, 2002).

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 (T. Dijkstra et al., 1999, 2010; Dufour & Kroll, 1995; Groot, 1992; 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 to 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., 2019a). Von Holzen & Mani (2012a) 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 (2012a) 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, Tsui, Bergmann, Black, Brown, Carbajal, & Wermelinger, 2021; Rocha-Hidalgo & Barr, 2023b). 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 arisen 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 to 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 (*cadira*<sub>CAT</sub>/*silla*<sub>SPA</sub> [chair]) and with *cullera*<sub>CAT</sub> [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 (cotxe<sub>CAT</sub>/coche<sub>SPA</sub>) and with cullera<sub>CAT</sub> [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.

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 to 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, Davies, 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 to participants' performance in the task. Third, previous

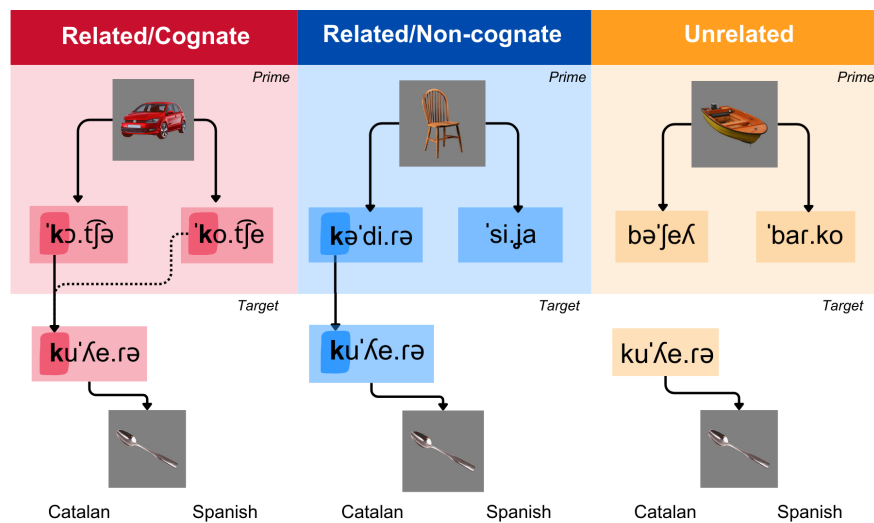


Figure 3.1: Predicted priming effects (or their absence) in the *Related/Cognate*, *Related/Non-cognate*, and *Unrelated* conditions, with examples for a participant tested in Catalan. Words represent lexical representations. Lexical representations of the task-relevant language (Catalan) are depicted 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.

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 is they were cognates; in the other half they were not phonologically related (non-cognates)<sup>1</sup>. 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

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<sup>1</sup>It was initially planned to collect 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 COVID-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.



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 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. The number of excluded testing sessions and participants is indicated between parentheses.

		Degree of Exposure		
Sample size		Age (months)	Spanish	Catalan
Test sessions	Participants	M (SD)	M (SD)	M (SD)

Study 2 - Bilingual						
Catalan dominant	65 (7)	46 (6)	25.19 (3.81)	37.65 (10.47)	61.98 (10.31)	
Spanish dominant	42 (7)	31 (7)	25.58 (3.41)	61.12 (11.00)	38.55 (10.42)	
Study 2 - Monolingual						
Catalan dominant	87 (8)	50 (7)	25.78 (3.91)	4.54 (5.98)	95.11 (6.17)	
Spanish dominant	46 (7)	28 (6)	25.18 (3.80)	90.80 (6.38)	8.74 (6.40)	
Study 1 - Monolingual						
English dominant	89 (21)	79 (21)	26.47 (4.05)	0.00 (0.00)	0.00 (0.00)	10

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.

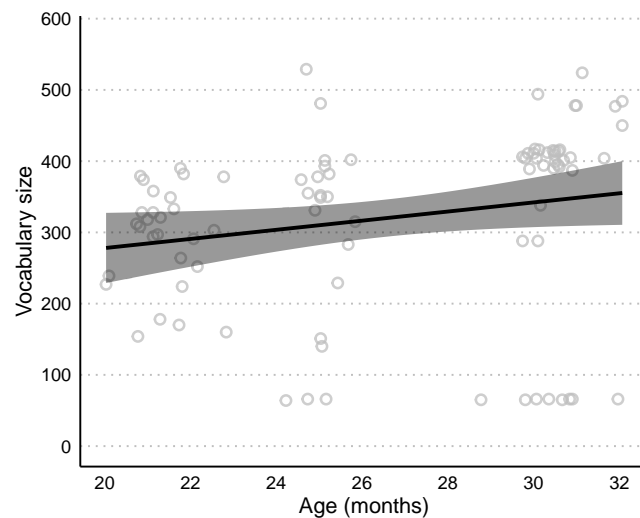


Figure 3.2: Participant receptive vocabulary sizes across ages and language profiles.

### 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., /'ti:/<sub>ENG</sub>[tree]–/'tɪk/<sub>ENG</sub>[truck]). In *Unrelated* trials, the prime and target labels did not share phonological

onset (e.g., /dɔ:/<sub>ENG</sub>[door]–/sɒk/<sub>ENG</sub>[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.

### 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 Appendix A for a detailed description of the stimuli). Table 3.2 shows a detailed

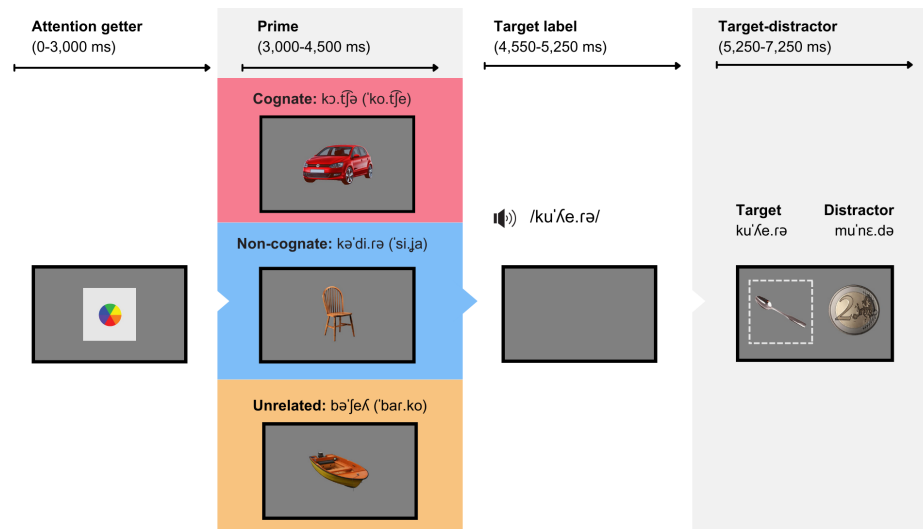


Figure 3.3: Experimental task design with examples in Catalan. In each trial, the prime image is presented in silence for 1,500 ms. Then the auditory target label is presented, and finally the target and distractor pictures are presented side-by-side for 2,000 ms. In cognate trials ( $n = 8$ ), Catalan *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.

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., 2019b) as counts per million words, and transformed into Zipf scores for easier cross-language comparison (Van Heuven et al., 2014b; Zipf, 1945). Audios had an average duration of 864.23 ms ( $SD = 148.53$ ,  $Range = 570\text{--}1,250$ ).

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

	# Phonemes		Frequency (Zipf)		Familiarity (%)	
	Prime	Target	Prime	Target	Prime	Target
Study 1: English						
Cognate	5.00 (1.24)	4.50 (1.34)	4.63 (0.53)	4.75 (0.39)	61.79 (10.04)	70.28 (15.28)
Non-cognate	5.75 (2.72)	4.50 (1.34)	4.75 (0.18)	4.75 (0.39)	61.43 (12.89)	70.68 (15.10)
Unrelated	5.24 (2.27)	4.33 (1.47)	4.68 (0.38)	4.73 (0.38)	67.04 (18.36)	73.35 (16.77)
Study 2: Catalan						
Cognate	4.50 (1.34)	4.88 (1.28)	5.07 (0.33)	4.83 (0.26)	85.00 (8.75)	69.17 (22.67)
Non-cognate	4.88 (1.47)	5.17 (1.33)	5.01 (0.37)	4.76 (0.25)	83.33 (10.65)	70.00 (21.57)
Unrelated	5.00 (1.51)	4.98 (1.31)	4.91 (0.31)	4.89 (0.25)	76.00 (15.25)	68.33 (22.12)

### Study 2: Spanish

Cognate	4.50 (0.88)	6.12 (1.55)	5.10 (0.31)	4.77 (0.29)	64.77 (24.06)	47.35 (24.06)
Non-cognate	5.25 (1.21)	5.92 (1.54)	4.94 (0.42)	4.71 (0.26)	68.18 (21.05)	50.00 (21.05)
Unrelated	4.62 (1.06)	5.73 (1.53)	4.94 (0.28)	4.69 (0.23)	64.20 (22.95)	45.64 (22.95)

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 ( $11.613^\circ$  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  $1929 \times 1080$  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 placed above the screen. After a successful calibration the experimenter trig-

gered 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., 2022 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:

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

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).

Table 3.3: Participant-level and trial-level sample size after applying inclusion criteria. The number of excluded participants and trials is indicated between parentheses.

	Trials
--	--------

	Participants	Unrelated	Non-cognate	Cognate
Study 1: English (Oxford)				
Monolingual (English)	89 (21)	1, 011 (733)	511 (360)	510 (359)
Study 2: Catalan/Spanish (Barcelona)				
Monolingual	133 (15)	1, 506 (862)	747 (437)	741 (443)
Bilingual	107 (14)	1, 140 (796)	555 (413)	596 (372)

**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.

**Target looking by participant  $i$  in session  $j$**

$$y_{ij} \sim \mathcal{N}(\mu_{ij}, \sigma_{ij})$$

**Distributional parameters:**

$$\eta'(\mu_{ij}) = (\beta_0 + u_{0_{ij}}) + (\beta_1 + u_{1_{ij}})\text{Condition} + \beta_2\text{Age} + \sum_{w=1}^k b_w \beta_{3_k} \text{Time} +$$

where:

$\eta'$  is the empirical logit of target fixations

$b_w$  is the cubic spline of the  $w$  basis function

$k$  is the number of knots in the spline ( $k = 8$ )

**Prior:**

$$\beta_{0-3} \sim \mathcal{N}(0, 0.5)$$

$$u_{0-1_{ij}} \sim \mathcal{N}(0, \sigma_{0-2})$$

$$b_w \sim \text{MVN}(0, \tau)$$

$$\sigma_{0-1}, \tau \sim \text{Exponential}(6)$$

$$\rho_{0-1} \sim \text{LKJCorr}(6)$$

where:

$\rho_{0-1}$  are the correlation parameters for  $\sigma_{0-2}$

(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 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 ( $\beta = 0.381$ , 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 ( $\beta = -0.023$ , 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 ( $\beta = 0.093$ , 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, we 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.



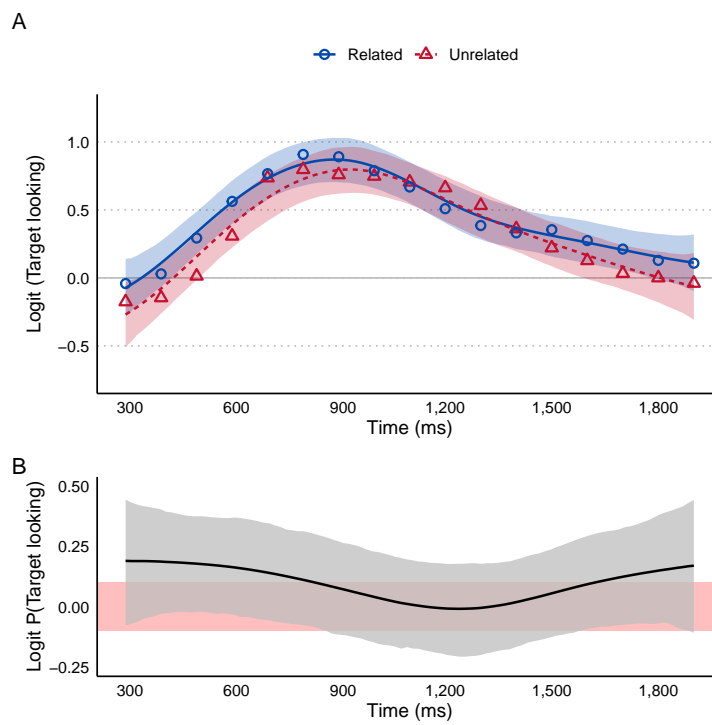


Figure 3.4: A) Posterior mean predictions of the time course of target fixation in the test phase. B) Posterior mean prediction of the time course of the differences in target looking time between conditions. Intervals represent the 95% CrI of the posterior predictions. Lines indicate the mean of the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

### 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) 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 3.4 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.

Table 3.4: Leave-one-out cross validation outcomes, comparing the predictive performance of the models in Study 1.

	ELPD	SE ELPD	ELPD (diff.)	SE ELPD (diff)
Model 1 (Age-by-condition)	−8,469.02	73.01	—	—
Model 0 (Age as main effect)	−8,469.15	73.02	−0.13	1.11
Model 2 (Vocabulary by-condition)	−8,469.37	73.09	−0.35	1.58

*ELPD*: sum of expected log pointwise predictive density for a new data set.

*SE (ELPD)*: standard error of the *ELPD*, which indicates the uncertainty about the predictive performance for unknown future data. *ELPD (diff)*: pairwise difference in *ELPD* for two models. The difference is computed relative to the model with lowest *ELPD* (best fitting model). *SE ELPD (diff.)*: standard error of component-wise differences of *ELPD* between two models.

### 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 (Related/Cognate and Related/Non-cognate) 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, Davies, 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 & Sebastian-Galles, 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, Ávila-Varela, 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.

Following the same procedure as in Study 1, we calculated participants' vocabulary size as the number of words that caregivers reported their child to *understand* or *understand and say* 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 Appendix B).

### **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 pic-

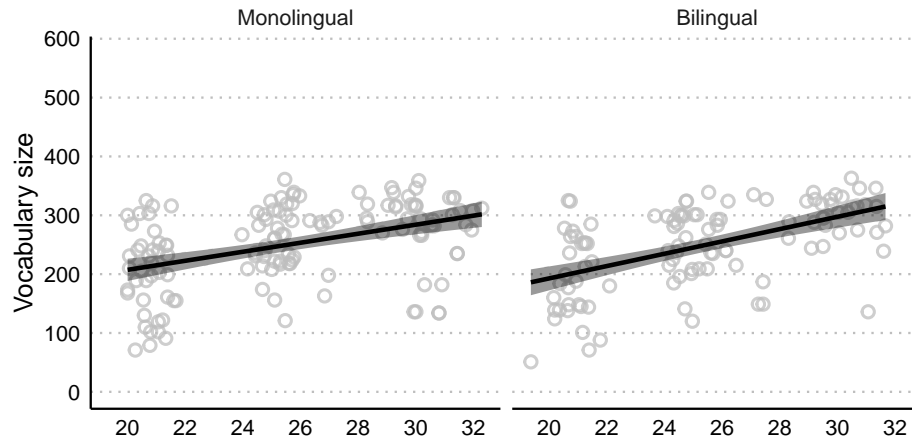


Figure 3.5: Participant receptive vocabulary sizes across ages and language profiles.

ture (e.g., prime: /'gos/<sub>CAT</sub>–/'pe.ro/<sub>SPA</sub>[dog], target: /'ka.za/<sub>CAT</sub>[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: /mi'ðo/<sub>CAT</sub> (/ka.l.θe'in/<sub>SPA</sub>)[dog], target: /mu'nɛ.ðə/<sub>CAT</sub>[coin]). In *Related/Cognate* trials, the target shared phonological overlap with both English and Spanish prime labels (e.g., prime: /'abrə/<sub>CAT</sub>–/'ar.βol/<sub>SPA</sub>)[tree], target: /ə'βɛ.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 consid-



ering 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 Garcia-Castro, Avila-Varela, et al. (2023). 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 ( $SD = 171.43$ ,  $Range = 860\text{--}1,550$ ), and Spanish audios had an average duration of 1,080.47 ms ( $SD = 134.58$ ,  $Range = 830\text{--}1,390$ ). 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 Appendix A 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  $1929 \times 1080$  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. Table 3.3 shows a detailed description of the trial attrition.

**\*\*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 ( $\beta = 0.215$ , 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 ( $\beta = 0.025$ , 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 ( $\beta = -0.014$ , 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 ( $\beta = 0.058$ , 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 ( $\beta = -0.011$ , 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 ( $\beta = -0.013$ , 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 ( $\beta = 0.093$ , 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 3.5. 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 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

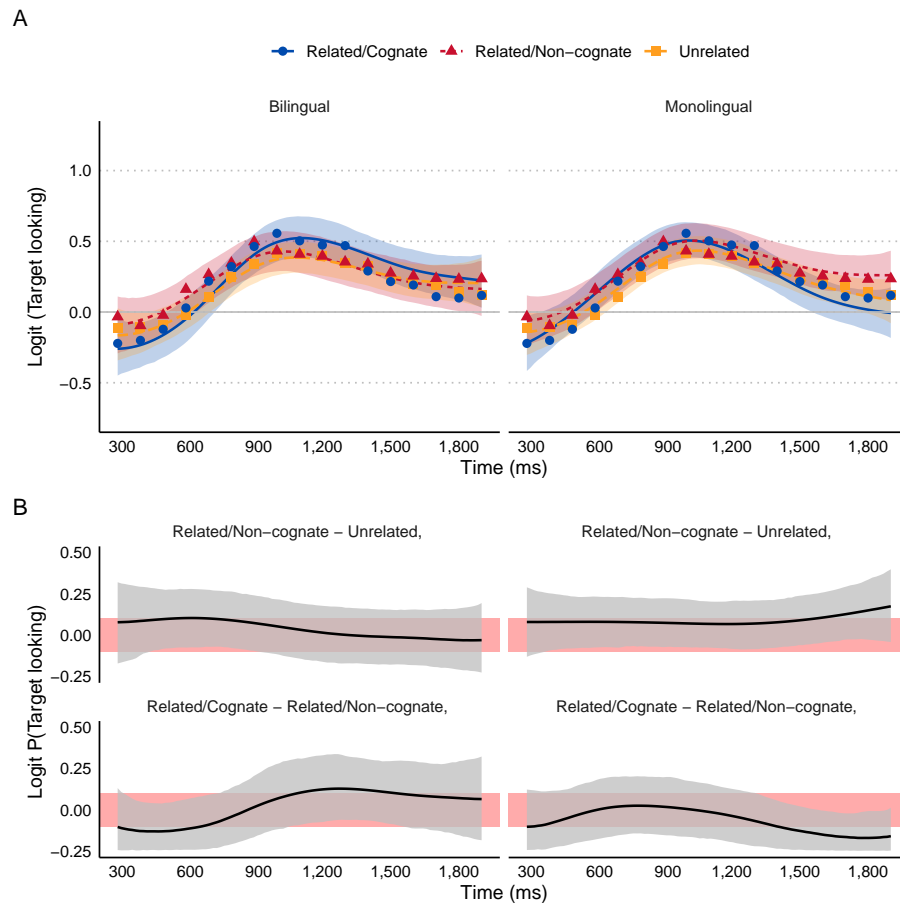


Figure 3.6: A) Posterior mean predictions of the time course of target fixation in the test phase. B) Posterior mean prediction of the time course of the differences in target looking time between conditions. Intervals represent the 95% CrI of the posterior predictions. Lines indicate the mean of the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

best-fitting model.

Table 3.5: Leave-one-out cross validation outcomes, comparing the predictive performance of the models in Study 1.

	ELPD	SE ELPD	ELPD (diff.)	SE ELPD (diff)
Model 0	−20,864.87	136.77	—	—
Model 1 (Age-by-condition)	−20,865.66	136.72	−0.79	1.97
Model 0 (Age as main effect)	−20,866.36	136.79	−1.49	1.18

*ELPD*: sum of expected log pointwise predictive density for a new data set.

*SE (ELPD)*: standard error of the *ELPD*, which indicates the uncertainty about the predictive performance for unknown future data. *ELPD (diff)*: pairwise difference in *ELPD* for two models. The difference is computed relative to the model with lowest *ELPD* (best fitting model). *SE ELPD (diff.)*: standard error of component-wise differences of *ELPD* between two models.

### 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, Davies, 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 nam-

ing 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 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., 2009a; 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 difficulty 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 to 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 af-

ter 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.

## 4 Discussion

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## **Glossary**

**Some term** The definition of this term

**Another term** The definition of this other term

**Get it?** Another term with its corresponding definitions

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