Comparing monolingual and bilingual language acquisition: phonemes and lexicon

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ABSTRACT

In the present dissertation we compared monolingual and bilingual language acquisition by exploring two main topics of the early bilingual language acquisition: the establishment of the phoneme system and the establishment of the lexico-semantic system. The first topic was addressed by assessing the possible influence of word-level information on phonetic learning in both monolinguals and bilinguals (both adults and infants). The development of the bilingual lexico-semantic semantic system has been approached by assessing the emergence of inhibitory semantic links in monolingual and bilingual toddlers.

Our results showed an impact of bilingualism concerning the use of word-level information in adults but not in infants. For this latter group, our results suggested more an impact of bilingualism on the discrimination abilities. Unfortunately our results for the last study did not allow us to conclude on the emergence of inhibitory semantic effects in the bilingual lexicon.

RESUMEN

En esta tesis doctoral comparamos la adquisición del lenguaje en monolingües y bilingües investigando dos temas centrales de la adquisición bilingüe temprana: el establecimiento del sistema fonético y el establecimiento del sistema léxico-semántico. El primer tema se ha abordado evaluando la posible influencia de información léxica (forma) sobre el aprendizaje fonético, la investigación ha estudiado tanto bebés y adultos monolingües y bilingües. Para el estudio del desarrollo del sistema léxico-semántico bilingüe se ha evaluado la aparición de conexiones semánticas inhibitorias en niños monolingües y bilingües. Los resultados sugieren un impacto del bilingüismo en el uso de información léxica (forma) en adultos, pero no en bebés. El estudio con bebés ha mostrado un impacto del bilingüismo en las capacidades discriminatorias. Los resultados del último estudio no permiten extraer conclusiones sobre la aparición de conexiones semánticas inhibitorias en el léxico bilingüe.

PREFACE

As a monolingual, born and raised in a strictly monolingual environment, the capacity for infants to learn two languages from birth has always captured my attention.

More generally, for the last two decades this same capacity has also constituted a topic widely investigated in the field of infant language acquisition. As a matter of fact, according to UNESCO data most of the world's populations are bilinguals, most of them from birth. Despite this, bilingual exposure has also been widely debated for several years with two confronting views, that Petitto and Kovelman (2003) elegantly named the "bilingual paradox": while ones support that infants can learn their two languages effortlessly, others are worried that learning two languages at the same time will produce delay and confusion.

The current literature in bilingual language acquisition could not provide clear evidences in favour of one of these two confronting views and overall remains inconclusive.

On the one hand, evidences have been found that bilingual infants reach their language developmental milestones at the same age as their monolingual peers. On the other hand, studies have suggested delays for bilingual infants when compared with monolinguals (see for reviews Höhle, Bijeljac-Babic & Nazzi, 2019; Costa & Sebastian-Galles, 2014; Sebastian-Galles, 2010).

Although a lot of research still remains to be done, in the present dissertation we will focus on two of bilingual language acquisition topics that, from our perspective, deserve special interest: the phoneme acquisition and the establishment of a semantic system.

The acquisition of the native phonetic categories is one of the major linguistic achievements in the first years of life. However, the current literature on this topic in bilingual infants is quite contradictory. This is especially the case for the Spanish-Catalan population that constitutes the population studied in this present dissertation. Here, we wanted to address the contradictory results found in Spanish-Catalan bilinguals from a different perspective by investigating the discrimination of a non-native contrast in both monolinguals and bilinguals.

The other topic addressed in this dissertation is the establishment of the bilingual semantic system. Surprisingly, this is a quite recent topic in the field of bilingual language acquisition especially concerning the emergence of inhibitory links in the bilingual lexicon. The present dissertation explored such topic again by testing monolingual and bilingual participants.

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1. INTRODUCTION

In the recent years, there has been a surge of research investigating the language acquisition in infants exposed to two languages from birth.

Investigations of bilingual language acquisition during the first two years of life have addressed numerous research lines. Concerning the initial steps of language acquisition, one main topic of investigation has been language discrimination. Indeed, one important difference for infants learning two languages is the need to differentiate the native languages present in the direct environment. This question has been addressed at different ages with both auditory and visual speech. Another important linguistic ability that has been extensively investigated is the capacity for bilingual infants to acquire their native phonetic categories in each of their language and this, for both consonant and vowel sounds.

Later in development, the bilingual lexical acquisition has constituted one of the main fields widely addressed. In this field, research has mainly focused on the development and the nature of the bilingual vocabulary containing both phonological and semantic information from the two languages. The processing of phonetic and phonological information when learning words has also been largely addressed, the study of the development of the bilingual semantic system only being an emergent topic of investigation (see for recent reviews, Höhle, Bijeljac-Babic & Nazzi, 2019; Werker, 2018; Costa & Sebastian-Galles, 2014; Sebastian-Galles, 2010).

Although a lot of research remains to be done, in the present dissertation, we will focus on two main topics of the bilingual language acquisition: the acquisition of a phoneme system and the establishment of the semantic system.

1.1 Acquisition of a phoneme system

The acquisition of a phoneme system has been largely investigated with both monolinguals and bilinguals. We will first present a short review of the literature on monolinguals and bilinguals and then we will describe theoretical accounts of the mechanisms underlying the establishing of the phonetic system.

1.1.1 Phonetic acquisition in monolinguals

Infants are born with the ability to discriminate most of the phonetic contrasts present in the world's language (Eimas et al., 1971). During the first year of life, language exposure will allow infants to group sounds into categories corresponding to their native language. More exactly, between 6 and 12 month-olds, the infant speech perception system specializes towards the native contrasts while the sensitivity for non-native contrasts declines (Werker & Tees, 1984; Kuhl et al., 2006; Narayan, Werker & Beddor, 2010).

The first study to report such effect in infants was conducted by Werker & Tees (1984). In their work, the authors tested 6-8-, 8-10- and 10-12-month-old English infants as well as 11-12 month-old Hindi and Thompson (a Salish language spoken by Native

Americans in British Columbia) infants on their perception of the Salish /k'i/-/q'i/ contrast and the Hindi /ʈa/-/t̪a/ contrast. Results with the English infants showed discrimination at 6-8 month-old but very poor discrimination by 10-12 months of age. Importantly, the Salish and Hindi infants showed discrimination of their respective native contrasts at 11-12 month-olds.

This process known as the perceptual reorganization shows that through language exposure, infants progressively lose their capacities to discriminate contrasts that are not present in the native language. Perceptual reorganization has been found to take place earlier for the vowel sounds at around 6 months of age, (Bosch & Sebastian-Galles, 2003; Cheour et al., 1998; Kuhl et al., 1992; Polka & Werker, 1994) and a bit later for the consonants (10-12 months of age at the earliest for the plosives, Werker & Tees, 1984). These results have been described in behavioural paradigms as well as with EEG (with both ERPs and time-frequency responses) and MEG techniques (Cheour et al., 1998; Rivera-Gaxiola, Silva-Pereyra & Kuhl, 2005; Bosseler et al., 2013; Ortiz-Mantilla, Hämäläinen, Musacchia & Benasich, 2013; Peña, Werker & Deheane-Lambertz, 2012).

1.1.2 Phonetic acquisition in bilinguals

The perceptual reorganization process has also been explored in bilingual infants but the results have been less conclusive. Since birth, bilingual infants have been exposed to two phonemic repertoires that overlap to different degrees depending on the languages they are exposed to. Despite this apparent difficulty, studies have reported the same pace of perceptual reorganization for native contrasts between bilinguals and monolinguals. Burns, Yoshida, Hill & Werker (2007) as well as Sundara, Polka & Molnar (2008) found that French-English bilinguals discriminated native consonant contrasts in both of their languages at the same age as their monolingual peers.

However, other studies measuring brain responses (mainly EEG and ERPs) during perceptual reorganization have reported less robust brain responses for native phonemes in bilingual infants compared to monolinguals, and this even when testing bilinguals in their dominant language (Garcia-Sierra et al., 2011; Ferjan-Ramirez, Ramirez, Clarke, Taulu & Kuhl, 2016). This pattern of results has been proposed to reflect an effect of amount of exposure: as bilinguals receive quantitatively less input in both of their languages, the improvement of the brain responses when perceiving native contrast may take place at a slower pace than for the monolinguals.

Of particular relevance for the present dissertation, research investigating perceptual reorganization for native contrasts with 8 month-old Spanish-Catalan bilinguals has yielded a complex pattern of data. In the first study addressing this question, Bosch & Sebastian-Galles (2003) tested 4- and 8 month-old infants from three different linguistic environments: Spanish monolinguals, Catalan monolinguals and Spanish-Catalan bilinguals. Using a familiarization-preference procedure, infants were tested on their discrimination of the /e-ɛ/ vocalic contrast that is phonemic in

Catalan but not in Spanish. Infants were familiarized with one vowel and then tested by being presented with the two vowels. Significant difference in looking times towards each type of vowel at test was taken as evidence of discrimination. At 4 month-olds, the results showed language-general discrimination abilities has the infants from all linguistic groups discriminated the contrast. At 8 months of age, as expected, the monolinguals showed a discrimination pattern corresponding to their linguistic environment. Spanish monolinguals showed a decline in sensitivity for non-native contrasts as they were no longer able to discriminate the /e-ɛ/ contrast while Catalan monolinguals maintained their discrimination of the contrast. To be noted, Catalan monolinguals showed a tendency to improve their discrimination abilities as they tend to show greater difference in looking times at 8 month-olds than at 4 month-olds. Unexpectedly, Spanish-Catalan bilinguals behaved as the Spanish monolinguals and did not discriminate the contrast, thus showing a specific developmental pattern. When testing an additional group of bilingual infants at 12 months of age, bilinguals showed a recovery of their discrimination abilities as they were able again to discriminate the contrast. These results suggest a U-shaped pattern concerning the discrimination of a native contrast for the bilinguals who appear to attune to their native vocalic system only by 12 month-olds.

This same U-shaped pattern was replicated with the vocalic /o-u/ contrast shared between Spanish and Catalan but not for the /e-u/ contrast (also shared between Spanish and Catalan; Sebastian-Galles & Bosch, 2009). For this last contrast, the authors suggested that the higher acoustical distance in the vocalic space may have facilitated the discrimination.

Taken together, the results of these two studies suggest that infants growing up in a bilingual environment show a specific developmental trajectory concerning the discrimination of some native contrasts that are acquired at a later age than the monolinguals.

However, a study by Albareda-Castellot, Pons & Sebastian-Galles (2011) questioned the explanation previously proposed. The authors tested again the same three linguistic populations of infants at 8 month-olds on their discrimination of the Catalan specific /e-ɛ/ contrast but with a different experimental method, an anticipatory eye movement task. Importantly, the authors used the same stimuli as in Bosch & Sebastian-Galles (2003). In the study, infants were presented on a screen with trials in which they saw a cueing visual stimulus (face of an Elmo character) disappearing behind a T-shaped occluder to reappear next at the upper right or upper left sides of the screen. Importantly, the side of the reappearance of the visual stimuli was contingent to the presentation of the same audio stimuli. For example, when hearing /deði/, the Elmo stimulus always reappeared on the upper right side of the screen while when hearing /dɛði/, it reappeared on the upper left side. This contingent presentation created the possibility for the infants to anticipate (anticipatory look) the location of the reappearance of the visual stimuli along the course of the experiment. However, these anticipatory looks could only occur if the infants discriminated the /e-ɛ/ contrast. Results showed that both Catalan monolinguals and

Spanish-Catalan bilinguals increased their correct anticipatory looks during the experiment while Spanish monolinguals did not. Contrary to the findings by Bosch & Sebastian-Galles (2003), these results suggest that 8-month-old-Spanish-Catalan bilinguals can discriminate the /e-ɛ/ contrast. Importantly, they also suggested that bilinguals' performance seem to depend on the experimental task used to assess their discrimination abilities. This dependence to the experimental task may indicate more fragile discrimination abilities in bilinguals compared to monolinguals.

1.1.3 Theoretical accounts of the mechanisms underlying perceptual reorganization

Accounts for the establishment of the phonetic categories have proposed that infants form their phonetic categories by attending to the distribution of sounds in the speech stream (bottom-up information) but also by attending to word-level information (top-down influences).

Contribution of Bottom-up information

There is abundant research showing early infants' sensitivity to the distributional information present in the speech stream. For example, both monolingual and bilingual infants show a preference for frequent phonotactic patterns over infrequent ones, showing that they are sensitive to the relative frequency of occurrence of segments in their language(s) (Jusczyk & Luce, 1994; Sebastian-Galles & Bosch, 2002). Studies in word segmentation have also showed the ability of 6 to 8 month-old monolingual and bilingual infants to use transitional probabilities between syllables to segment the speech stream (Saffran, Aslin & Newport, 1996; Bosch et al., 2013).

One popular bottom-up mechanism for the emergence of the phonetic categories is the distributional learning account proposed by Maye, Werker and Gerken (2002). According to this account, infants form phonetic categories by tracking the distribution of sounds within the acoustic space. Using the preferential looking procedure, Maye and colleagues explored the effects of exposure to different frequency distribution by testing 6 and 8 month-olds on their discrimination of the native English voiced [d] (as in **d**ay) and voiceless unaspirated [t] (as in s**t**ay). Importantly, both sounds are not contrastive in English and native English listeners can perceive them as members of the same category [d]. In the Maye et al study, infants were familiarized with a continuum of synthesized [da]-[ta] tokens running from [d] to [t], but critically according to two different statistical distributions: unimodal or bimodal. For the infants familiarized with the unimodal distribution, the tokens from the center of the continuum (ambiguous tokens between [da] and [ta]) were the more frequent while for the infants familiarized with the bimodal distribution the tokens from the two endpoints of the continuum were the more frequent. At test, only the infants familiarized with the bimodal distribution displayed evidence of discriminating the endpoint [da]-[ta] stimuli (see Maye, Weiss and Aslin, 2008 for a more difficult contrast). These results suggest that infants are sensitive to distributional information and are able to use it to form categories.

To our knowledge, the only model proposed to account for language acquisition in both monolinguals and bilingual infants is PRIMIR (Processing Rich Information from Multidimensional Interactive Representations) proposed by Curtin, Byers-Heinlein & Werker (2011). When accounting for the acquisition of the phonetic categories, PRIMIR considers that both monolinguals and bilinguals use bottom-up information. The model only considers the influence of top-down information when meaning is involved, such as for instance, when infants learn the words *doll* and *ball*. Because we are interested in the influence of top-down information not related to meaning we do not further elaborate this model.

Contribution of Top-down information

Feldman, Myers, White, Griffiths, and Morgan (2013) showed that infants are also sensitive to top-down information when learning native phonetic categories. One limit of the distributional learning account is that sound categories present a high degree of overlap in the acoustic space. That is, the same sound may belong to different phoneme categories. In some cases, the overlapping distribution should mislead infants into creating a unique category. The authors proposed that the *word context* in which the overlapping sounds appear may be an additional word-level cue to help infants separate sounds. Even if two sounds present an overlapping distribution (for example /ɪ- iː/ in English), they are usually heard in different word contexts such as ‘treat’ for the sound /iː/ and ship for the sound /ɪ/. The clearly different word forms of ‘treat’ and ‘ship’ may inform infants to separate the /iː/-/ɪ/ phonetic categories. In contrast, sounds heard in similar word contexts (minimal pairs, e.g ship/sheep) would inform infants that these sounds might belong to the same category. But minimal pairs present in the early vocabulary (such as the abovementioned *doll* and *ball*) represent a tiny percentage of the situations where two phonemes appear. Importantly, this proposal considers that learners can acquire sounds *without* meaning or referents when using top down information. Feldman et al., (2013) proposed that exposure to sounds appearing in dissimilar word context (or non-minimal pairs, e.g treat/ship) would help infants separate overlapping sounds before semantic information is available.

Feldman et al. (2013) tested this hypothesis and assessed the possible influence of word contexts on the perception of a native overlapping contrast (/ɑ/-/ɔ/) by American-English 8 month-olds. They familiarized infants with synthesized stimuli forming a continuum from /ɑ/ (*ah*) to /ɔ/ (*aw*) embedded in disyllabic pseudo-words. These pseudo-words were used to create two word-context conditions: the Minimal Pair condition, where the vocalic contrast appeared in all the pseudo-words (/litʰ**ɑ**/, /litʰ**ɔ**/, /gutʰ**ɑ**/, /gutʰ**ɔ**/) and the Non-Minimal Pair condition where the contrast appeared in distinct word contexts (either /litʰ**ɑ**/-/gutʰ**ɔ**/ <u>or</u> /litʰ**ɔ**/-/gutʰ**ɑ**/). In each condition, the syllables *li* and *gu* served as word context cues that could indicate that the /tʰ**ɑ**/ and /tʰ**ɔ**/ sounds belonged to one or two categories. The Minimal Pair condition presented the /ɑ/-/ɔ/

vowels interchangeably with the syllables *gu* and *li*, possibly indicating that the two sounds might belong to the same category. The Non-Minimal Pair condition was divided into two sub-conditions: half of the participants heard the vowel /ɑ/ only with the syllable *li* and the vowel /ɔ/ only with the syllable *gu* while the other half of the participants heard the vowel /ɑ/ only with the syllable *gu* and the vowel /ɔ/ only with the syllable *li*.

Using the Head-turn Preference Procedure, 8 month-olds were first familiarized according to either the Minimal Pair or the Non-Minimal Pair conditions. Discrimination of the /ɑ/-/ɔ/ contrast was then assessed by presenting two types of test trials: *Non-Alternating* trials containing the test syllables repeating one of the two test vowels (e.g: /t^h**ɑ**/-/t^h**ɑ**/-/t^h**ɑ**/-/t^h**ɑ**/… or /t^h**ɔ**/-/t^h**ɔ**/-/t^h**ɔ**/-/t^h**ɔ**/…), and *Alternating* trials containing test syllables alternating the two test vowels (e.g: /t^h**ɑ**/-/t^h**ɔ**/-/t^h**ɑ**/-/t^h**ɔ**/…). Results showed that only the infants familiarized with the Non-Minimal Pair condition discriminated the contrast as they looked significantly longer to the Non-Alternating trials than to the Alternating trials.

Interestingly, similar results were found with adult participants with a phonetic category learning task. After being passively familiarized according to one of the two word context conditions, participants were tested on their discrimination of the test syllables /t^hɑ/ vs. /t^hɔ/. Results showed that participants familiarized with the Non-Minimal Pair condition assigned the test syllables to different categories significantly more often than the participants familiarized with the Minimal Pair condition.

Taken together, these results showed that 8-month-old and adult monolingual participants are sensitive to the word context in which sounds appear and that this information can constrain the way they categorize native sounds. However, the possible influence of such information has not been investigated yet in the case of a non-native contrast.

1.1.4 Conclusion

Overall, the investigation of the perceptual reorganization for native contrasts in Spanish-Catalan bilinguals remains inconclusive. In the present dissertation, we want to address this question from a different perspective by investigating the discrimination of a non-native contrast at 8 month-olds in both monolinguals and Spanish-Catalan bilinguals. To do so, we will replicate the study by Feldman et al. (2013) and test both monolingual and simultaneous Spanish-Catalan bilinguals on their discrimination of a non-native contrast. As Feldman et al. (2013), we will test both adults as well as 8 month-olds. Adult participants will be tested first to control for the relevance of the non-native contrast used later with the 8 month-olds.

1.2 Acquisition of a semantic system

The second topic addressed in the present dissertation is the establishment of a semantic system. Contrary to their monolingual peers, bilinguals have the supplementary task to organize their semantic system in both of their languages. However, to date little is known on how the information in the bilingual mental lexicon is organized.

Research with monolinguals has widely addressed several aspects of word learning such as the representation of phonology (Bouchon et al., 2015; Hallé & de Boysson-Bardies, 1996; Mani & Plunkett, 2007; Poltrock & Nazzi, 2015; Swingley & Aslin, 2000; Swingley, 2005 among others) and the association of labels and objects (Stager & Werker, 1997). Recently, the organization of the semantic system has also been explored with semantic priming studies (Arias-Trejo & Plunkett, 2009, 2013; Chow et al., 2016, 2019; Styles & Plunkett, 2009).

Research with bilinguals has also addressed the same topics of the representation of phonology (Ramon-Casas et al., 2009; Ramon-Casas, Fennell & Bosch, 2017) and the association of labels and objects (Werker, Fennell, Corcoran & Stager, 2002; Fennell & Byers-Heinlein, 2014; Mattock, Polka et al., 2010). Again, it is not until very recently that the organization of the bilingual semantic system has been addressed with semantic priming studies (Jardak & Byers-Heinlein, 2019; Rämä, Sirri & Goyet, 2018; Singh, 2014; Sirri & Rämä, 2019). However, when compared to the monolinguals, the literature remains scarce.

We will first present a review of the literature on semantic priming studies in both monolinguals and bilinguals.

1.2.1 Semantic priming studies

Plunkett and colleagues performed a series of pioneering studies investigating the organization of the semantic system using the priming technique in monolinguals toddlers (Arias-Trejo and Plunkett, 2009, 2013; Styles and Plunkett, 2009). The authors used a variation of the Intermodal Preferential Looking (IPL) task. In a typical IPL study, toddlers are presented with two pictures on a screen (e.g a DOG and a BOAT) and hear a target word (e.g, “dog”). Given that toddlers know the target word, they show a preference for the target picture demonstrated by greater looking times towards the named target picture compared to the distractor picture. In a semantic-priming IPL study, the auditory target word is preceded by a prime word either semantically related to the target (e.g, “cat”, related-prime trials) or semantically unrelated to it (e.g, “plate”, unrelated-prime trials), such as “Yesterday I saw a cat (prime). Dog (target)!”. Significant differences in looking times towards the target picture between the related-prime and unrelated-prime trials are considered as evidence of semantic priming.

Using this paradigm, Styles and Plunkett (2009) as well as Arias-Trejo and Plunkett (2009, 2013) reported semantic priming in both 21- and 24 month-olds but not at 18 month-olds. In their studies, the younger infants displayed similar looking times towards the target regardless of the nature (related or unrelated) of the prime suggesting only facilitatory effects of a prime over a target regardless of their semantic relationship. The older infants behaved differently as they looked significantly more in the related-prime trials compared to the unrelated-prime trials. Furthermore, the looking times to the target were significantly above chance only in the related-prime trials. These results suggested that target recognition was impaired by the presentation of an unrelated prime in a forward fashion. Moreover, the fact that only the older toddlers showed inhibitory effects suggested that semantic activation may be modulated by the number of words in the toddlers' lexicon.

This same paradigm has been used to explore semantic priming in bilingual toddlers. To our knowledge, the first study exploring semantic priming in bilingual toddlers was conducted by Singh (2014) with English-Mandarin 30 month-old bilinguals. The author tested the participants both within (prime and target in the same language) and across their two languages (prime and target in different languages). Results showed an effect of language dominance as toddlers looked significantly more to the target in the related-prime trials compared to the unrelated-prime trials but only when the prime was in the toddlers' dominant language. Furthermore, the looking times to the target were significantly above chance only in the related-prime trials indicating that the unrelated prime impaired the process of the target recognition. These results suggest both within and across language priming effects in the toddlers' dominant language.

Jardak & Byers-Heinlein (2019) explored semantic priming effects with English-French 24- and 30 month-old bilinguals. When testing 24 month-olds on within language priming (i.e prime and target in the same language) in each of their languages, the authors did not find effects of semantic priming as the participants displayed similar looking times towards the related- and unrelated prime target indicating only facilitatory effects of a prime over a target independently of their semantic relationship. When testing 30-month-olds on both within and across language priming, the authors found a different pattern of results. Toddlers looked significantly more to the related- than to the unrelated-prime target indicating semantic priming effects. Again, the looking times were at chance only for the unrelated-prime trials suggesting an interference of the unrelated prime on target recognition. However, contrary to Singh (2014) these results were found in both of the bilinguals' languages. The authors proposed that the different pattern of results may be due to the different pairs of languages learned by the participants.

Altogether, these results suggest the appearance of semantic priming effects at 30 month-olds in bilingual toddlers. However, the use of a cognitively demanding within-subject design (participants tested both within and across their languages during the same session) and the lack of control of some stimuli limit their interpretation.

A second group of studies have used ERPs to investigate the same questions in both 18 month-olds (Rämä, Sirri and Goyet, 2018) and 2-to-4-years-old bilingual children (Sirri and Rämä, 2019). Contrary to all the previous studies just reviewed, the authors did not use the IPL technique, instead they only presented auditory stimuli. Participants were passively presented with pairs of prime and target words either semantically related or unrelated while ERPs responses were recorded. Rämä, Sirri and Goyet (2018) tested 18-month-olds only their dominant language and Sirri and Rämä (2019) tested children in both languages. In both studies the results suggested the presence of a semantic priming effect. In particular, they observed larger amplitudes in the N400 component for the unrelated pairs as compared to the related ones. In the second study, the effect seemed to be present only in the dominant language. Although the results of these studies are very suggestive, they suffer from some methodological limitations, such as atypical scalp distributions of the responses and marginal significances of relevant effects and interactions.

In summary, the results of the semantic priming studies in bilinguals do not provide a coherent picture, yet they suggest that by 30- but not by 24 months of age, the bilingual semantic system contains both facilitatory and inhibitory links both within and across the bilinguals' two languages. As expected, these effects would to be stronger for the dominant language compared to the non-dominant one.

1.2.2 Backward semantic inhibition

The papers previously reviewed have evidenced inhibitory effects of an unrelated prime on target recognition in a forward fashion. Indeed, the mental lexicon contains both inhibitory and facilitatory connections.

The forward semantic inhibition comes from the observation that participants recognize slower a target word when it is preceded by a semantically unrelated word than when it is preceded by a neutral stimulus (e.g a tone). For example, the target word “window” will be recognized slower if it has been preceded by the word “elbow” than by a tone. This result suggests that the switch from “elbow” to “window” had a higher cost than processing the word “window” after hearing a semantically neutral stimulus, i.e. the tone.

Two recent studies with monolingual toddlers have also reported inhibitory effects of an unrelated prime on target recognition in a backward fashion, or backward semantic inhibition (Chow, Aimola-Davies, Fuentes & Plunkett, 2016; 2019). Compared to the forward semantic inhibition explained above, the experimental procedure of backward semantic inhibition adds another level to the stimuli presented to the participants. Backward semantic inhibition is observed when participants are presented with three stimuli, two of which are semantically related such as for example the word “door” followed by the word “elbow” and then the word “window”. In order to activate the word “elbow” participants will need to inhibit the previously activated word, “door”. Importantly here, this inhibition will spread to the word “window” due to its semantic relationship to “door”. Consequently, the activation of the word “window” will be impaired when the participants will have to activate it. Critically, as for the forward semantic inhibition effect, backward semantic inhibition is not observed if the second stimulus is a neutral tone such as “door-*tone*-window”. In this case, participants maintain the activation of the word “door” when presented with the neutral string of letters. This maintenance of the activation of the word “door” consequently facilitating the activation of the subsequently presented semantically related word, “window”. The term of *backward* inhibition comes from the fact that participants had to “come back” to a previously attended category.

Effects of backward semantic inhibition were first reported in adults when switching between semantic categories during a modified lexical-decision task (Fuentes, Vivas and Humphreys, 1999, Experiment 2). In the study (see Figure 1.1 below), participants were presented with a written prime word (e.g “dog”) followed by an intervening stimulus which was either a printed word from a different semantic category (e.g “sea”) or a neutral string of letters (e.g “XXX”). In the test phase, participants were asked to decide if the target was either a word or a non-word. Importantly, the target and prime words were either semantically related (e.g. dog (prime) and cat (target)) or not (e.g dog-finger). Results showed that when the intervening stimulus was a word, participants displayed longer reaction times to the related-prime target than to the unrelated-prime target. In contrast, when the intervening stimulus was a neutral string of letters (e.g “XXX”), reaction times did not significantly differ between the related- and unrelated-prime targets.

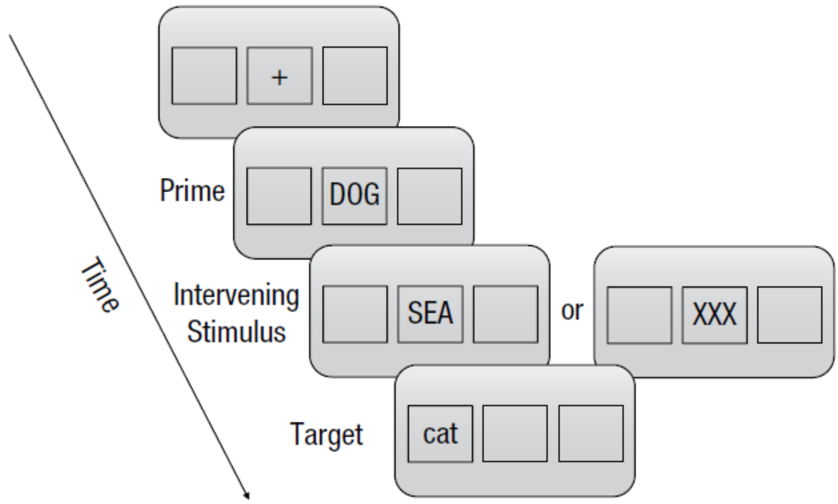

Figure 1.1 Example of a trial sequence of the lexical decision task used by Fuentes, Vivas and Humphreys (1999, Experiment 2). In each trial, participants were presented with a prime word followed by an intervening stimulus both at the center of the screen. The intervening stimulus was either a semantically unrelated word or a neutral string of letters. Finally, a target was presented either on the right of left side of the screen and participants had to make a lexical decision. (Picture reproduced from Chow et al., 2016).

The authors proposed that when participants shifted their attention between the semantic categories of the prime and intervening stimulus, it resulted in the inhibition of the former. This inhibition spread to the semantically related target consequently impairing the participants' response time to the related-prime target. Importantly, the absence of effects when the intervening stimulus was a neutral string of letters suggests that backward semantic inhibition only occurs when switching within the semantic space.

In an adaptation of the adults' procedure, Chow, Aimola-Davies, Fuentes and Plunkett (2016, 2019) investigated backward semantic inhibition in 24- and 18 month-olds with an eye-tracker method. Toddlers were presented on a screen the pictures of three types of stimuli one after the other: a prime, an intervening stimulus and a pair of target and distractor (see Figure 4.1, page 116 for a detailed description of the paradigm). The presentation of the prime and intervening stimulus was accompanied by their corresponding auditory words but there was no labelling of the target or distractor pictures. As in the adult study, the prime and target pictures were either semantically related (e.g chair-table) or unrelated (e.g chair-hat). The intervening stimulus was either a word (a picture and its corresponding label, intervening-word condition) or a tone (a checkerboard picture with a tone, intervening-tone condition). Thus, like for the adult study a shift to a different semantic category was induced for the intervening-word condition only.

Chow et al. (2016) first tested a group of English 24 month-olds. The time-course eye-tracking data of the test phase (when toddlers were presented with the target and distracter pictures) were analysed with growth curve modelling analysis. The growth curve analysis is a multilevel regression analysis that allows the description of the overall group pattern over time instead of collapsing all the data into single data point (such as it is done when computing total looking time in a window of analysis). Doing this, growth curve analysis has the advantage of providing information about when conditions or groups differ as two groups can have the same average but with very different time courses. Overall, the analysis showed that when the intervening stimulus was a word, toddlers looked significantly less at the related-prime target than at the unrelated-prime target (see Figure 1.2). In contrast, when the intervening stimulus was a tone, toddlers looked significantly more at the related- than at the unrelated-prime target. In other words, Chow et al. (2016) observed backward semantic inhibition in the intervening word condition and facilitation in the intervening tone condition.

In a follow up study, Chow et al. (2019) explored the backward semantic inhibition in younger toddlers, at 18 month-olds. As mentioned above, Plunkett and colleagues found that 24- and 21 month-olds but not 18 month-olds displayed effects of semantic priming suggesting the presence of inhibitory effects only for toddlers with greater vocabulary. Accordingly, Chow et al. (2019) expected backward semantic inhibition to appear only in younger toddlers with large vocabularies. This was assessed by splitting the 18 month-olds into large and small vocabulary size groups. Results showed that while both toddlers with large and small vocabulary size showed facilitation in the intervening tone condition, only toddlers with large vocabulary size displayed backward semantic inhibition in the intervening-word condition. This last result is thus in line with the previous results found by Plunkett and colleagues suggesting that vocabulary size modulates the appearance of inhibitory connections in the toddlers' lexicon.

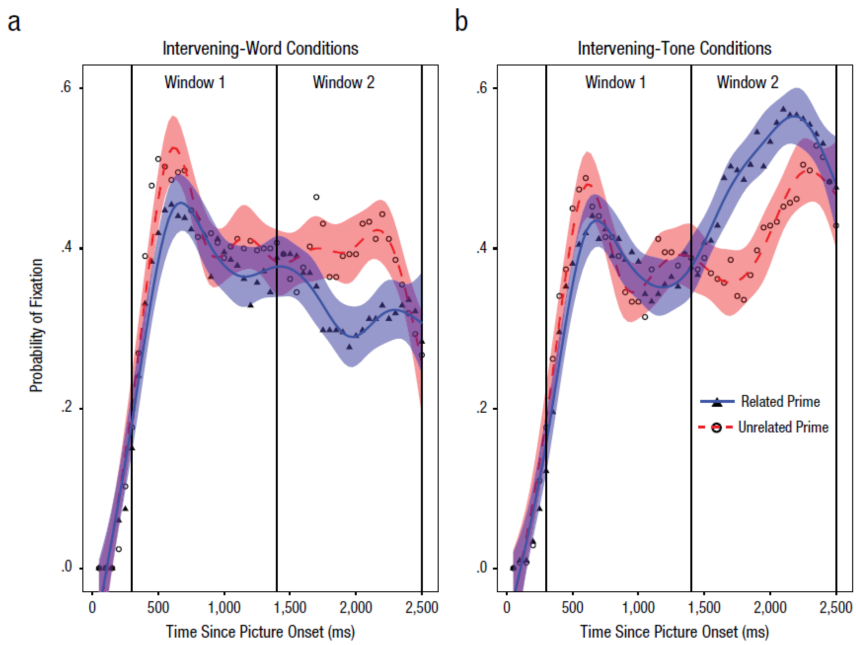

Figure 1.2 Results of the time-course eye-tracking data obtained by Chow et al. (2016) in the test phase on their experiment (when participants were presented with the target and distracter picture). Points indicate fixation data aggregated by 50-ms time bins, lines indicate smoothing splines and shaded ribbons indicate 95% confidence intervals based on smoothing splines. Backward semantic inhibition was observed in the second time window. The probability of participants fixating on the target was higher when preceded by an unrelated prime than a related one in the Intervening word condition. However in the intervening tone ones, the probability to fixate on the target was higher when preceded by a related prime. Growth curve analysis allows for a determination of the time-course of the facilitatory or inhibitory effects. (Picture reproduced from Chow et al., 2016).

1.2.3 Conclusion

Data on the organization of semantic information remains scarce especially for the bilingual toddlers. However, the available results suggest that inhibitory links emerge in the toddlers' lexicon with the increase of the vocabulary size. This modulation represents a window of opportunity to investigate the type of information responsible for such effects with bilingual toddlers. Indeed, in the bilingual lexicon, word forms and concept do not occur in a one-to-one correspondence as bilinguals ultimately learn two word forms (one in each language) corresponding to a unique concept. Moreover, during development, bilinguals know some words in one language, some in the other language and some in both languages.

As a consequence, bilingual toddlers know less words in each of their languages (Hoff et al., 2012; Hoff, Rumiche, Burridge, Ribot, & Welsh, 2014) but they have an equivalent number of concepts for which they know at least one word (conceptual vocabulary). Thus, bilinguals' word knowledge can be assessed differently: based on the word forms they know in the language of test and based on their "conceptual vocabulary".

In the present dissertation, we want to investigate the appearance of inhibitory effects in bilingual toddlers by exploring the backward semantic inhibition. To do so, we will replicate the study by Chow et al. (2019) by adapting the stimuli from English to Catalan. To investigate the modulation of vocabulary size on the emergence of the backward semantic inhibition effect, participants will be split into large and small vocabulary size groups. Groups will be determined in two different ways: based on the number of concepts for which bilinguals know at least one word in one of their languages (conceptual vocabulary) and number of words known in the target language (Catalan vocabulary). Monolingual participants will be also tested as control for the stimuli used with the bilinguals.

1.3 Present research

The present dissertation comprises three experimental sections.

The Experimental sections 1 and 2 (Chapters 2 and 3) addressed the acquisition of a phoneme system in bilinguals by investigating the possible influences of word-level information not related to meaning when learning a non-native contrast in both adults (Experimental section 1) and infants (Experimental section 2).

In the Experimental section 1, we tested both adult monolinguals (Experiment 1) and adult simultaneous Spanish-Catalan bilinguals (Experiment 2) on their discrimination of the British-English contrast /ɒ-ʌ/ with a phonetic category learning task. In a control study (Experiment 3) we assessed our participants' baseline discrimination abilities of the non-native contrast.

In the Experimental section 2, using the Head-Turn Preference Procedure we tested both 8-month-old monolinguals (Experiment 1) and Spanish-Catalan bilinguals (Experiment 2) on their discrimination of the same British-English contrast.

The Experimental section 3 (Chapter 4) addressed the establishment of a semantic system in bilinguals by exploring the backward semantic inhibition in 18- to 24-month-old toddlers. Using an eye-tracker method, we tested Catalan monolinguals (Experiment 1a) and Spanish-Catalan bilinguals (Experiment 1b). Following the lack of replication in the results of Experiment 1, a new group of Catalan monolinguals (Experiment 2a) and Spanish-Catalan bilinguals (Experiment 2b) were tested with a different set of stimuli.

The final Chapter 5 will present a summary of the main results and final conclusions together with future lines of research.

2. EXPERIMENTAL SECTION 1

COMPARING MONOLINGUALS AND BILINGUALS LEARNING A NON-NATIVE PHONEME CONTRAST: ADULTHOOD

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2.1 Abstract

The mechanisms underlying the acquisition of new second language (L2) sounds by adult learners still remain unclear. When investigating possible top-down influences on the learning of a native vocalic contrast, Feldman et al. (2013) showed that, contrary to the assumption that meaning is required to constrain phonetic learning through minimal pairs, adults are also sensitive to word-level information not related to meaning. Here, we investigated the effectiveness of word-level information when learning an L2 vocalic contrast and if simultaneous bilingual exposure had an influence on how such information is used. Adapting the study by Feldman et al. (2013), we tested monolingual and simultaneous bilingual adults' discrimination abilities of a foreign contrast by manipulating familiarisation to tokens that included or not minimal pairs. Our results showed that while monolingual adults'

performance was better after familiarisation to stimuli not including minimal pairs, replicating the pattern found by Feldman et al. (2013), simultaneous bilinguals did not show differences between the two types of familiarisation. These results extend the influence of word-level information to the case of L2 vocalic contrast learning and provide evidence that simultaneous bilingual exposition had an influence on the use of word-level information.

Keywords: adults, simultaneous bilingualism, second language acquisition, phonetic category learning, top-down influences

2.2 Introduction

While the adult speech perception system is tuned to perceive the phonemic contrasts belonging to their native language(s), adult listeners still have difficulties to perceive non-native contrasts (Werker & Tees, 1984a). These reduced capacities are not universal and depend on the native language of the listener that influences the way second language (L2) sounds are perceived. One of the first examples reported in the literature were the difficulties for Japanese listeners to discriminate the English /r/-/l/ contrast (Goto, 1971; Miyawaki, Jenkins et al., 1975) or for English listeners to discriminate the dental-retroflex Hindi /t/-/ţ/ contrast (Werker, Gilbert, Humphrey & Tees, 1981). The identification of the mechanisms underlying the acquisition and production of new L2 sounds by adult learners remains a main subject of research.

Three of the most popular models are the Perceptual Assimilation Model (PAM; Best, 1995 and PAM-L2, Best & Tyler, 2007), the Speech Learning Model (SLM; Flege, 1995) and the L2 Linguistic

Perception Model (L2LP; Escudero, 2009 and L2LP revised, Leussen & Escudero, 2015). Although the three models differ when considering the nature of the underlying representations of phonemes (acoustic for SLM, articulatory for PAM and phonological for L2LP), they consider bottom-up/distributional information of L1 and L2 sounds as predictors of how L2 sounds will be perceived. The three models propose that the relative distribution of the L1 and L2 phonemes in the acoustic space determines if a new L2 sound will be easy or difficult to learn. Following this rationale, an L2 contrast easy to learn would be a contrast whose two phonemes have an acoustic distribution close to phonemes belonging to two separated L1 categories (Two-Category assimilation (PAM), Similar scenario (L2LP)). For example, the acoustic distribution of the Ethiopian ejective contrast /p'/-/t'/ is similar to the one of the English /p/-/t/ contrast, thus facilitating its learning. One difficult L2 contrast to learn would be a contrast whose two phonemes have an acoustic distribution close to phonemes belonging to a single L1 category (Single Category assimilation (PAM), New scenario (L2LP)). This is the case of the Hindi dental retroflex /t/-/ţ/ contrast whose phonemes have an acoustic distribution similar to the English single category /t/. In more rare cases, an L2 contrast may be identified as non-speech (noise) as it would be considered as being outside of the native phonological space (Non Assimilable (PAM)). This is for example the case of some Zulu clicks contrasts for English learners. According to PAM, because the sounds are highly deviant from any native sounds, their discrimination is expected to be good to very good.

In addition to distributional information, the PAM-L2 and L2LP (revised) also propose a top-down influence of the lexicon in the way that lexicon provide semantic information that may help separate two L2 phonemes. The PAM-L2 considers that the acquisition of L2 lexical items may exert a linguistic pressure for L2 learners to improve their perception of L2 contrasts. In other words, the bigger the L2 lexicon the better the perception will be. The L2LP (revised) is more specific and proposes a lexical feedback through the minimal pairs. These specific words differ by only a single sound and have a different meaning (e.g sheep /ʃiːp/ and ship /ʃɪp/). Thus, the discovery that 'sheep' containing the sound /iː/ and 'ship' containing the sound /ɪ/ have a different meaning may prompt an L2-English learner to consider the two phonemes /iː/ and /ɪ/ as contrastive and create two categories.

Research on L2 contrast training has applied this bottom-up theoretical approach and used pre-lexical (phonetic or phonological) information to teach new L2 contrasts. Minimal pairs have been extensively used as stimuli, both as natural and synthesized tokens, in the most popular L2 phoneme training techniques: fading technique (Jamieson & Morosan, 1986; Kondaurova & Francis, 2010), inhibitory training and natural correlation training (Kondaurova & Francis, 2010), alternative forced task with feedback (Francis & Nusbaum, 2002). Such studies reported enhancement of the participants' discrimination abilities and led the researchers to conclude that exposure to minimal pairs was the best way to learn a new L2 contrast.

Feldman, Myers, White, Griffiths and Morgan (2013) recently proposed a different role of the lexicon in phonetic learning, a role not involving the use of word meaning. In their account, it is the phonological word context in which sounds appear that may serve as a contextual cue to form phonetic categories. Although two sounds may have a close/overlapping distribution in the acoustic space (for example /iː/-/ɪ/ in English), learners hear them in different word contexts, such as ‘treat’ for the sound /iː/ and ‘ship’ for the sound /ɪ/. As a matter of fact, minimal pairs (e.g sheep/ship) constitute a minority of the contexts where two phonemes appear in the speech stream. The different word forms of ‘treat’ and ‘ship’ provide an additional word-level cue to the learners to separate the two phonetic /iː/ and /ɪ/ categories. Leaving aside meaning, exposure to sounds appearing in similar word contexts (or minimal pairs, e.g sheep/ship) would inform learners to group these sounds together, making their discrimination difficult. Conversely, exposure to sounds appearing in very dissimilar word contexts (or non-minimal pairs, e.g treat-ship) would facilitate their discrimination for the learners. The relevance of such word contexts would be particularly important when starting to learn a new language, when word meaning may not be well established and therefore it may not exert a strong force.

Feldman et al. (2013) tested this hypothesis by assessing the possible role of word-level information on the perception of a vocalic contrast with American English adults and 8 month-old infants. Both groups were tested on their discrimination of a native overlapping vocalic contrast /ɑ/-/ɔ/. The choice of a vocalic contrast was motivated by the fact that at the acoustic level, vowel sounds tend to have an important overlapping distribution. One of the most popular mechanisms proposed for the establishment of the phonetic categories is the bottom-up distributional learning mechanism (Maye & Gerken, 2000). This mechanism allows learners to form phonetic categories by tracking the statistical distribution of speech sounds within the acoustic space. Thus, exposure to a bimodal distribution of sounds would lead to the formation of two categories while exposure to a unimodal distribution would lead to the formation of a unique category. However, through this mechanism, an overlapping distribution might be mistaken with a unimodal distribution, possibly hindering the correct establishment of the category. Word-level information would be an additional cue for the learners to separate the sounds.

Feldman et al. (2013) used synthesized stimuli forming a continuum from /ɑ/ to /ɔ/ that were then embedded in disyllabic pseudo-words: /lit^{h}**ɑ**/-/lit^{h}**ɔ**/ and /gut^{h}**ɑ**/-/gut^{h}**ɔ**/. These pseudo-words were used to create two word-context conditions: the Minimal Pair condition, where the vocalic contrast appeared in all the pseudo-words (/lit^{h}**ɑ**/, /lit^{h}**ɔ**/, /gut^{h}**ɑ**/, /gut^{h}**ɔ**/) and the Non-Minimal Pair condition where the contrast appeared in distinct word contexts (/lit^{h}**ɑ**/-/gut^{h}**ɔ**/ or /lit^{h}**ɔ**/-/gut^{h}**ɑ**/). For both conditions, the syllables *li* and *gu* were used as word context cues possibly indicating the participants that the /t^{h}ɑ/ and /t^{h}ɔ/ sounds belonged to one or two categories. In the

Minimal Pair condition, the vowels /ɑ/ and /ɔ/ were presented interchangeably with the syllables *gu* and *li*, suggesting the listener that the two vowels might belong to the same category. In the Non-Minimal Pair condition, half of the participants heard the vowel /ɑ/ only with the syllable *li* and the vowel /ɔ/ only with the syllable *gu*. Conversely, the other half of the participants heard the vowel /ɑ/ only with the syllable *gu* and the vowel /ɔ/ only with the syllable *li*. According to their hypothesis, Feldman and colleagues expected the distinct word contexts in the Non-Minimal pair condition to facilitate the discrimination by indicating the listeners to separate the /ɑ/-/ɔ/ vowels.

The participants were tested with a phonetic category learning task and completed two identical familiarization-testing blocks. Familiarization was done through passive listening according to one of the two word context conditions. Half of the participants were familiarized with the Minimal Pair condition while the other half of the participants was familiarized with the Non-Minimal Pair condition. Participants' discrimination was then assessed in an AX discrimination task by calculating their sensitivity score (d') to the /ɑ/-/ɔ/ contrast. Results in the second test block showed that the participants familiarized with the Non-Minimal Pair condition assigned the test syllables /t^hɑ/ and /t^hɔ/ to different categories significantly more often than the participants familiarized with the Minimal Pair condition. These results suggest that adult listeners are sensitive to word-level information not related to meaning and that this information can constrain the way they categorize native sounds.

Feldman et al's study trained participants to better discriminate a native contrast, it remains unknown to which extend new L2 phoneme learning can be influenced by phonological word contexts too. The present research has two main goals. First, we want to investigate the effectiveness of word-level information when learning a L2 phonetic category. The second goal is to assess if early bilingual exposure may have an impact on the way such information is used. Bilinguals have been exposed to two languages and had to master two phonological systems. Research with bilinguals has shown that they are sensitive to small sub-phonemic/acoustic information in tasks related to word identification, in infants (Mattock, Polka et al. 2010; Fennell & Byers-Heinlein, 2014), and in adults. Ju and Luce (2004) showed that Spanish-English bilinguals are sensitive to subtle cross-linguistic allophonic variations during a spoken word recognition task. Using eye-tracking method, they tested highly proficient Spanish-English bilinguals on their sensitivity to cross-linguistically differences between Spanish and English voiceless stop consonants. Compared to their English counterpart, Spanish word-initial voiceless stop consonants have a shorter voice onset time (VOT) and are not aspirated. Ju and Luce (2004) asked their participants to select a target object named in Spanish among four pictures. In addition to the target, the pictures included an interlingual distracter whose name in the L2 language was phonologically similar to the target word in the L1 language (e.g 'pliers' for the Spanish target word 'playa' (beach)) and two control distracter whose names were phonologically different to the target word. Importantly, the participants heard two types of target words: Spanish words with Spanish word-initial appropriate VOT and Spanish words with English word-initial appropriate VOT. Results showed that Spanish-English bilinguals fixated the interlingual distracter significantly longer than the control distracters only when listening to Spanish words with English VOT suggesting that bilinguals use fine-grained allophonic variation to access language-specific lexical representations. Taken together, the results of the investigations with both infants and adults point in the direction of bilinguals having an increased sensitivity to small sub-phonemic/acoustic information. This increase may also generally favor bilinguals in learning new phonemic contrasts.

We adapted the study by Feldman et al. (2013) and tested individuals raised as monolinguals (Spanish or Catalan) and simultaneous bilinguals (Spanish-Catalan) on their discrimination of an L2 vocalic contrast difficult to perceive by natives of these languages, the British English /ɒ/-/ʌ/ contrast. These vowels exist neither in Spanish nor in Catalan. Previous research with Spanish and Italian native speakers showed their difficulty to discriminate this contrast (Escudero & Chládková, 2010; Flege & MacKay, 2004). Given that the Italian and Catalan vocalic repertoires are similar and that the Spanish repertoire contains even less vowels than the Catalan one, one may assume the /ɒ/-/ʌ/ contrast as difficult to learn by Spanish and Catalan natives. Contrary to the original study, as the contrast was already non-native for our participants and to approach natural learning environments, we used naturally produced tokens instead of synthesized tokens with a vocalic continuum. A corpus of pseudo-words was created by embedding the test vowels in two-syllable non-words: */lit*ʰ***ɒ****/-/lit*ʰ***ʌ****/* and /*nut*ʰ***ɒ****/-/nut*ʰ***ʌ**/. Participants were familiarized according to two word-context conditions: the Minimal Pair condition where the vocalic contrast appeared in all the pseudo-words (e.g, */lit*ʰ***ɒ****/,* /*nut*ʰ***ɒ****/, /lit*ʰ***ʌ****/, /nut*ʰ***ʌ**/) and the Non-Minimal Pair condition where the contrast appeared in distinct word context (e.g, */lit*ʰ***ɒ****/-/nut*ʰ***ʌ**/ or */lit*ʰ***ʌ****/-/nut*ʰ***ɒ****/*). Participants were then tested on their discrimination of two syllables /tʰɒ/, and /tʰʌ/. As in the original study, syllables *nu* and *li* were used as word context that could potentially inform the participants whether /tʰɒ/ and /tʰʌ/ belonged to one or two categories, depending on the familiarisation phase.

A series of three experiments has been implemented. In the first experiment, we investigated if word-level information can influence how Spanish and Catalan monolinguals perceive an L2 vocalic contrast. In the first experiment, we expected to replicate the pattern of results found by Feldman et al. (2013) with the monolingual participants familiarized with the Non-Minimal pair condition being more likely to categorize the [ɒ] and [ʌ] sounds in two different categories than the participants familiarized with the Minimal Pair condition. In the second experiment, we tested Spanish-Catalan simultaneous bilinguals with the same paradigm to evaluate the possible impact of bilingualism on the use of word-level information. We expected the simultaneous bilinguals to behave differently from their monolingual peers. As precocious bilingual exposure may have increased their sensitivity to sub-phonemic information, we expected bilinguals to be better than the monolinguals and to show a better discrimination of the /ɒ/-/ʌ/ contrast in both experimental conditions.

The third experiment was a control study. Feldman et al. (2013) argued that as only the participants in the Non-Minimal Pair group increased their discrimination score between the two test blocks, the clearer word context of this condition *facilitated* the discrimination of the /ɑ/-/ɔ/ vocalic contrast. However, according to their theoretical proposal, it could also be that exposure to Minimal Pairs hindered discrimination. They did not test this hypothesis by controlling the baseline discrimination of the contrast. In order to assess the role of both the Minimal Pair and Non-Minimal Pair conditions, we measured discrimination of the /ɒ/-/ʌ/ contrast in two new groups of participants who completed only the two test blocks, with no previous familiarization. An additional group of native British English speakers was tested to better assess the discrimination of the /ɒ/-/ʌ/ contrast by our non-native participants.

2.3 Experiment 1

In this experiment we assessed if Spanish or Catalan monolinguals are sensitive to word-level information when learning an L2 vocalic contrast.

2.3.1 Methods

Participants

Forty-eight adult participants were tested and included in the analysis. Nine additional participants were tested but not included in the analysis because they did not reach the minimum number of valid trials in one of the conditions (see Results and Discussion section). Participants were raised as either Catalan monolinguals (N=24) or Spanish monolinguals (N=24). Following previous studies (Sebastián-Gallés & Soto-Faraco, 1999; Pallier, Colomé & Sebastián-Gallés, 2001; Sebastián-Gallés, Echeverria & Bosch, 2005) and as the vast majority of the adults in Barcelona use both Spanish and Catalan in their daily life, participants were considered as monolingual if they have been exposed to only one language at home before 3 years of age.

Participants were students from the University Pompeu Fabra (age range: 18-34 years old) who reported no hearing problems. They were paid 10€/hour. The experiment was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). Written informed consent was obtained from the participants before the experiment was conducted.

During the visit, information about the formal education in English received by the participants has been collected. On average, participants started learning English at school at age 6 (mean= 5.90, SD=2.20 years). They were asked to fill a language questionnaire where they self-rated their comprehension, reading, fluency, pronunciation and writing skills on a ten-point scale (1= very poor to 10= native proficiency). The details of the English scores are shown in Table 2.1.

Table 2.1. Details of the English scores for the Monolingual participants (Spanish and Catalan).

Variable	Minimum	Maximum	Mean	SD
Onset of listening to English (years)	3	14	5.9	2.2
Comprehension score (1-10)	4	10	8.3	1.1
Reading score (1-10)	5	10	8.6	1.1
Fluency score (1-10)	3	10	7.7	1.3
Pronunciation score (1-10)	2	10	7.3	1.5
Writing score (1-10)	1	10	7.9	1.6

Stimuli

The audio stimuli were naturally-produced tokens and consisted in 2 test syllables /tʰɒ/ and /tʰʌ/ and in 10 filler syllables (*bu*, *mu*, *bo*, *ji*, *go*, *li*, *nu*, *di*, *ku* and *po*).

Six to eight tokens of each of these syllables were recorded by a male British English native speaker in a sound-attenuated booth. Four similar tokens of each syllable were selected and equalized to 350ms with the Audacity software (version 2.0.2 Audacity® recording and editing software[1]).

Disyllabic pseudo-words were constructed through concatenation of the test and filler syllables for a total of 4 test pseudo-words (*/litʰɒ/, /litʰʌ/, /nutʰɒ/ and /nutʰʌ/*) and 4 filler pseudo-words (*gobu*, *mubo*, *poji* and *diku*).

[1] Audacity software is copyright 1999-2019 Audacity Team. The name Audacity is a registered trademark of Dominic Mazzoni.

Thirty-two exemplars of each */litʰɒ/-/litʰʌ/* and */nutʰɒ/-/nutʰʌ/* pairs were created by combining the four tokens of *nu* or *li* with each of the eight */tʰɒ/ and /tʰʌ/* test syllables. In total, 64 test tokens were created.

Sixteen tokens of each filler pseudo-words *gobu*, *mubo*, *poji* and *diku* were obtained by using all possible combinations of the four tokens of each syllable for a total of 64 filler tokens.

Apparatus

Participants were tested in an acoustically attenuated booth. The experiment was controlled with custom-made software using MATLAB (version 2014a with Psychtoolbox 3.0.12, script adapted from Feldman et al., 2013).

The audio stimuli were presented through Sennheiser PC 151 noise cancelling headphones while instructions in the dominant language of each participant (Catalan or Spanish) were presented on the screen.

Procedure

We used the same procedure as Feldman et al. (2013). At the beginning of the experiment, each participant was assigned to one of the two experimental conditions: the Minimal Pair or Non-Minimal Pair condition. They completed a familiarization-test procedure repeated twice: after being familiarized and completing the first test block, participants were familiarized and tested a second time. Participants were told that they will hear a list of words in a language that was neither Catalan nor Spanish and that they will be then asked to make decision about the vocalic sounds of this language.

In the familiarization blocks, participants heard 128 tokens presented in a random order and separated by an 800 milliseconds inter-stimulus interval. Half of the tokens were the filler tokens (*mubo*, *poji*, *gobu*, and *diku*, n=64) while the other half were the test tokens (*/litʰɒ/, /litʰʌ/, /nutʰɒ/ and /nutʰʌ/*, n=64).

All the participants heard the same filler tokens but depending on the condition they have been assigned to, each participant heard the test tokens in different word context. The participants assigned to the Minimal Pair condition heard all the exemplars possible of the four test tokens (*/litʰ**ɒ**/, /litʰ**ʌ**/, /nutʰ**ɒ**/ and /nutʰ**ʌ**/*) for a total of 64 tokens. The participants assigned to the Non-Minimal Pair condition were divided into two sub-conditions. Half of the participants heard 16 */nutʰ**ɒ**/* tokens and 16 */litʰ**ʌ**/* tokens repeated twice per block. They never heard the */nutʰ**ʌ**/* or */litʰ**ɒ**/* tokens. Conversely, the other half of participants heard 16 */nutʰ**ʌ**/* tokens and 16 */litʰ**ɒ**/* tokens repeated twice per block and never heard the */nutʰ**ɒ**/* or */litʰ**ʌ**/* tokens. The familiarization lasted 3 minutes and a half.

In the test blocks, participants were presented with two syllables separated by a 800ms inter-stimulus interval[2]. They were asked if the vowel contained in each syllable seemed equivalent between them or not. The instructions were given at the beginning of the test block and were as follow:

[2] Due to a technical error, one participant did the experiment with a 930 ms inter-stimulus interval. Removing this participant from the analysis did not change the results, therefore this subject was kept in the sample.

> In this part, you will listen to pairs of syllables and you have to decide if the vowels are the same o not in the language you have just heard.
> For example, in Spanish, the words SAL (salt) and SOL (sun) have different vowels.
> If you consider that the two vowels are different (like in SAL-SOL), you have to answer « DIFFERENT »
> But if you hear two different pronunciations of the same syllable (e.g SAL-SAL) you have to answer « EQUIVALENT » even if the syllables may sound slightly different.
> Even if you are not sure of your answer, please try to make a guess.

Participants were instructed to give their answer as quickly and accurately as possible by pressing one of two different keys on the keyboard corresponding to the *equivalent* and *different* response. Responses and reaction times for each trial were collected.
Two types of contrasts were presented to the participants in the test phase: the test contrast (2 different pairs of /tʰʌ/ vs. */tʰɒ/*) and the control contrast ("*bo*" Vs. "*bu*").
Participants heard a total of 128 trials in each test block, half of them being *different* trials. For these *different* trials, participants heard two tokens of each stimulus type for each contrast (e.g., /tʰʌ/ vs. */tʰɒ/* or "bo" vs. "bu").
For the *same* trials, the same procedure as in Feldman et al. (2013) was used. For the test contrast, the participants heard two identical

tokens (e.g., */tʰɒ/1* vs. */tʰɒ/1*) whereas for the control contrast the participants heard two non-identical tokens of the same syllable (e.g., “bo1” vs. “bo2”). This was done to ensure that participants were correctly following the instructions of making category judgements instead of lower-level acoustic judgements.

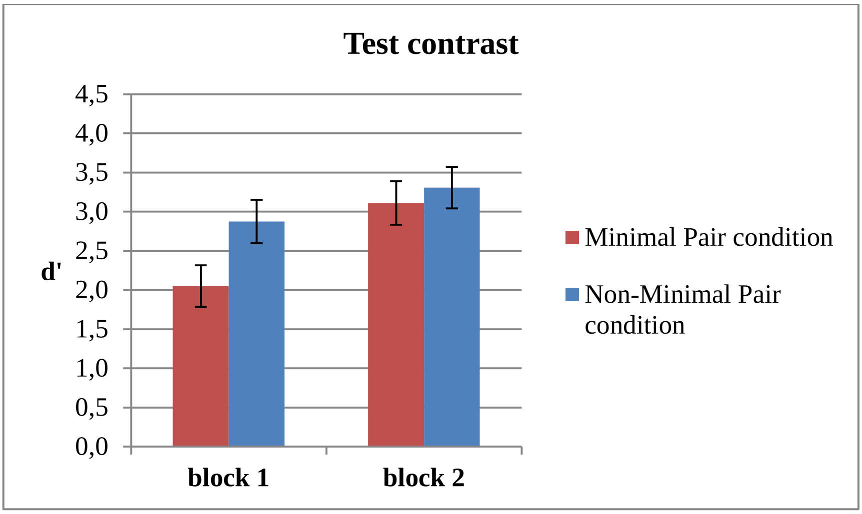
In total, participants heard 32 *different* and 32 *same* trials for each type of contrasts (test and control).

2.3.2 Results and Discussion

Analysis

As in Feldman et al. (2013) a pre-analysis of the data was done based on the reaction times. Trials for which the participants answered before the second stimulus was displayed were discarded from the analysis, as well as trials for which the participants had reaction times superior to two standard deviations from a participant’s mean reaction time for a particular response on a particular class of trial in a particular block. An average of 13 trials (SD=2.12) were discarded from the analysis representing 5% of the total number of possible responses. Following this analysis, one participant was excluded due to a too high number of trials discarded. The d prime (d’) score was calculated from the remaining responses for each contrast in each test block. As in Feldman et al. (2013), a value of 0.01 was substituted for any trial type for which the participants answered “equivalent” to all trials and a value of 0.99 was substituted for any trial type for which the participants answered “different” to all trials. Participants who did not obtain a mean d’ score superior to 3 for the control contrast (“*bo*” vs. “*bu*”) in the two test blocks were excluded from the analysis (N=4) as well as participants who obtained a score of 0 in both test blocks for the test contrast (N=4). The mean d’ scores for each contrast are described in Figure 2.1.

For the test contrast (*/tʰɒ/* vs. */tʰʌ/*), we conducted the same analysis as Feldman et al. (2013). A 2 x 2 Condition (Minimal Pair vs. Non Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed and yielded a main effect of Block ($F(1, 46)=20.31$, $p<0.001$). This main effect of Block reflects higher mean d’ scores in the second test block than in the first test block (3.21 vs. 2.46 respectively). There was no significant main effect of Condition ($F(1, 46)=2.18$, $p=0.146$). The analysis also showed a marginal Condition by Block interaction ($F(1, 46)=3.58$, $p=0.064$) reflecting a larger increase in mean d’ scores between the two test blocks in the Minimal Pair condition as compared to the participants in the Non-Minimal Pair condition. Test of simple effects showed a significant effect of Condition in the first test block with the participants in the Non-Minimal Pair condition having significantly higher mean d’ scores than the participants in the Minimal Pair condition ($t(46)= -2.15$, $p=0.037$). There was no significant effect of Condition in the second test block.



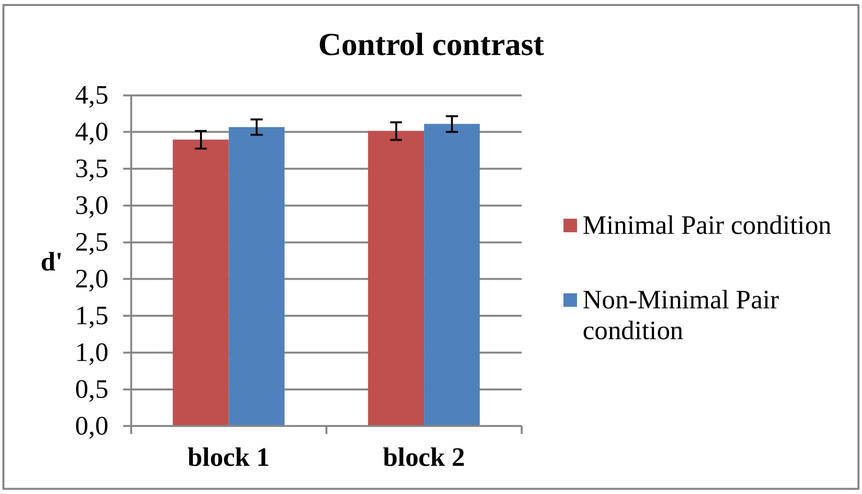


Figure 2.1. Mean d prime scores and standard errors in the two test blocks for the Test contrast (top) and control contrast (bottom) in the Minimal Pair (red) and Non-Minimal Pair (blue) conditions for the Monolingual participants.

The Catalan vocalic repertoire contains more vowels than the Spanish repertoire (8 versus 5). To check if the difference in the number of vowels in the phonetic repertoire had any influence on the discrimination of the /ɒ/-/ʌ/ contrast, we run a post-hoc analysis and separated the participants in each condition according to their first language (Spanish or Catalan). In the Minimal Pair condition, 14 participants were Spanish monolinguals and 10 were Catalan monolinguals. In the Non-Minimal Pair condition, 10 participants were Spanish monolinguals and 14 were Catalan monolinguals. The scores obtained by each linguistic group are detailed in Table 2.2.

A 2 x 2 x 2 Condition (Minimal Pair vs. Non Minimal Pair) x Language (Catalan vs. Spanish) x Block (1 vs. 2) mixed ANOVA was conducted and showed a main effect of Block ($F(1,44)=17.98$, $p<0.001$) reflecting again higher mean d' scores in the second test block than in the first test block (3.21 vs. 2.46 respectively). Importantly, there was no significant main effect or interactions of language suggesting that both Spanish and Catalan monolinguals behaved similarly.

Table 2.2. Mean d' scores and standard deviations obtained by the Spanish and Catalan participants for each condition in each test block.

	Minimal Pair condition			
Linguistic group	Test Block 1		Test Block 2	
	mean	SD	mean	SD
Spanish monolinguals (N=14)	2,04	1,22	3,32	1,31
Catalan monolinguals (N=10)	2,06	1,46	2,81	1,43
	Non-Minimal Pair condition			
Linguistic group	Test Block 1		Test Block 2	
	mean	SD	mean	SD
Spanish monolinguals (N=10)	2,87	1,48	3,20	1,62
Catalan monolinguals (N=14)	2,88	1,33	3,38	1,08

For the control contrast (“bo” vs. “bu”), a 2 x 2 Condition (Minimal Pair vs. Non Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed and none of the tested factors yielded significance. As expected participants scored very high in this contrast: the average d’ score was 3.95 for the participants in the Minimal Pair condition and 4.09 for the participants in the Non-Minimal Pair condition.

These results replicate the pattern found by Feldman et al. (2013) but contrary to them, the effect was observed in the first test block. This may be due to several reasons. First, the use of naturally produced tokens instead of synthesized ones with a vocalic continuum may have facilitated the task for our participants. Second, the instructions given to our participants may have also facilitated their task, as they were specifically instructed to pay attention to the vowel sounds presented in the pairs of syllables. Feldman et al. (2013) did not specify if their test sounds differed according to their vocalic or consonant sounds. This may have disturbed their participants who may not have known at first to exactly which sounds they had to pay attention.

The difference in the number of vowels in the vocalic repertoire did not have any influence on our participants’ performance as both Catalan and Spanish monolinguals performed similarly.

The results of Experiment 1 show that word-level information not related to meaning can constrain the way monolingual adults perceive a L2 vocalic contrast. Experiment 2 investigates if bilingualism modulates this sensitivity to word-level information.

2.4 Experiment 2

As they have been exposed to two languages since birth, simultaneous bilinguals may be more sensitive to sub-phonemic/acoustic information. As a result, they may perform better than the monolinguals and show a better discrimination of the L2 contrast in both experimental conditions.

2.4.1 Methods

Participants

Forty-eight simultaneous Spanish-Catalan bilingual adult participants were tested and included in the analysis. Eight additional participants were tested but not included in the analysis because they did not reach the minimum number of valid trials in one of the conditions (see Results and Discussion section). Following previous studies (Sebastián-Gallés & Soto-Faraco, 1999; Pallier, Colome & Sebastián-Gallés, 2001; Sebastián-Gallés, Echeverria & Bosch, 2005) and as the vast majority of the adults in Barcelona use both Spanish and Catalan in their daily life, participants were considered as bilinguals if they have been exposed to both languages from birth. Participants were students from the University Pompeu Fabra (age range=18-33 years-old) who reported no hearing problems. They were paid 10€/hour. The experiment was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the

Parc de Salut Mar). Written informed consent was obtained from the participants before the experiment was conducted.

As in Experiment 1, information about the formal education in English received by the participants has been collected. On average, they started learning English at school at age 6 (mean= 6.04, SD=2.18 years). The participants filled the same language questionnaire about their comprehension, reading, fluency, pronunciation and writing skills as in Experiment 1. The details of the English scores are shown in Table 2.3.

Table 2.3. English scores for the Spanish-Catalan bilinguals (the questionnaire used a ten-point scale: 1= very poor to 10= native proficiency).

Variable	Minimum	Maximum	Mean	SD
Onset of listening to English (years)	3	13	6.0	2.2
Comprehension score (1-10)	5	10	8.0	1.0
Reading score (1-10)	6	10	8.5	1.1
Fluency score (1-10)	3	10	7.7	1.4
Pronunciation score (1-10)	4	10	7.1	1.2
Writing score (1-10)	5	10	7.8	1.1

Stimuli, apparatus and procedure

Same as in Experiment 1.[3]

2.4.2 Results and Discussion

Analysis

The same pre-processing of the data as in Experiment 1 was done based on the reaction times. An average of 13 trials (SD=2.76) were

[3] As in Experiment 1, one participant did the experiment with a 930 ms inter-stimulus interval. Removing this participant from the analysis did not change the results, therefore this subject was kept in the sample.

discarded from the analysis representing 5% of the total number of possible responses. The d' score was calculated from the remaining responses for each contrast in each test block. As in Experiment 1, participants who did not obtain a mean d' score greater than 3 for the control contrast ("bo" vs. "bu") in the two test blocks were excluded from the analysis (N=3) as well as participants who obtained a score of 0 in both test blocks for the test contrast (N=5). Results are shown in Figure 2.2.

For the test contrast (*/tʰɒ/* vs. */tʰʌ/*), a 2 x 2 Condition (Minimal Pair vs. Non Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed and yielded a main effect of Block ($F(1, 46)=21.73$, $p<0.001$). This reflects higher mean d' scores in the second test block than in the first test block (3.63 vs. 2.95 respectively). There was no significant main effect of Condition ($F<1$). Contrary to the Experiment 1, the Condition by Block interaction did not reach significance ($F<1$).

To parallel the analysis of Experiment 1, an analysis restricted to the first block was performed. Test of simple effects did not show a significant effect of Condition ($F<1$) with the participants in the Non-Minimal Pair condition having similar mean d' scores (2.82) compared to the participants in the Minimal Pair condition (3.08), ($t(46)<1$).

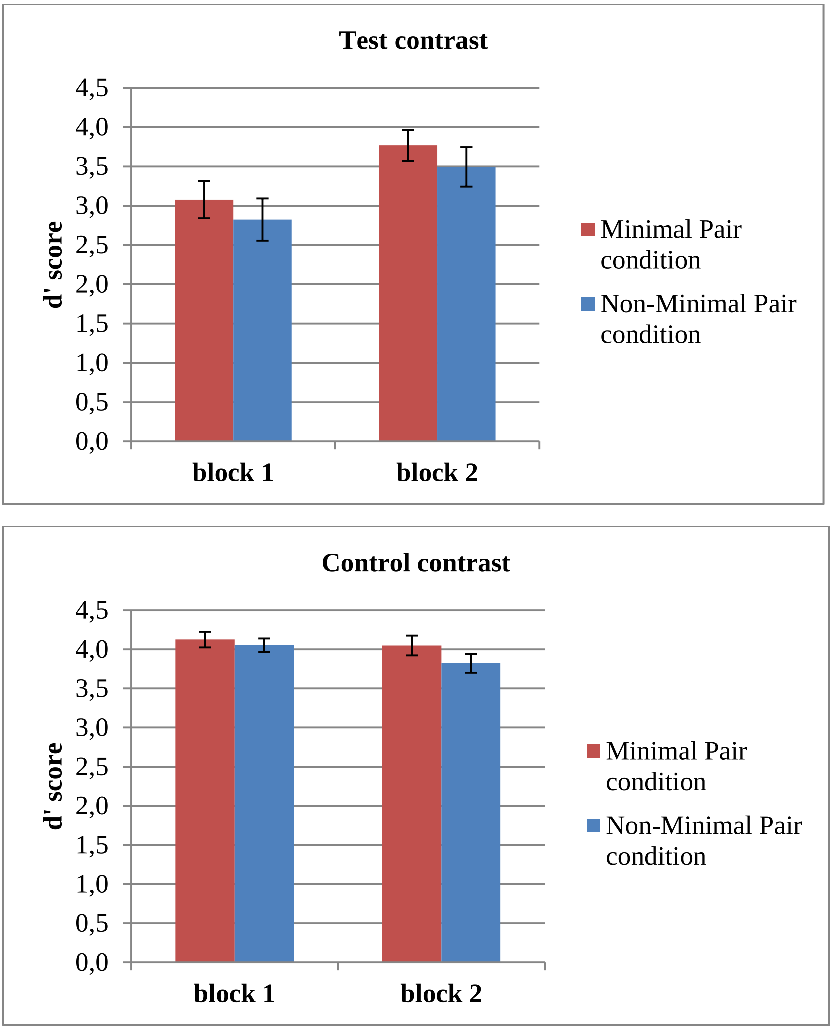


Figure 2.2 Mean d prime scores and standard errors in the two test blocks for the Test contrast (top) and control contrast (bottom) in the Minimal Pair (red) and Non-Minimal Pair (blue) conditions for the Bilingual participants.

For the control contrast ("bo" vs. "bu"), a 2 x 2 Condition (Minimal Pair vs. Non Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed and showed a marginal effect of Block ($F(1, 46)=3.33$, $p=0.074$). This reflects lower mean d' scores in the second test block than in the first test block (3.93 vs. 4.09 respectively). There was no other significant main effect or interaction. As for the monolinguals, simultaneous bilinguals scored very high in this contrast: the average d' score was 4.09 for the participants in the Minimal Pair condition and 3.94 for the participants in the Non-Minimal Pair condition.

One potential explanation for this lack of effect for the test contrast could be that participants were at ceiling. Participants in this experiment scored very high already in the first block (Minimal Pair: mean=3.08, SD=1.16; Non-Minimal Pair: mean=2.82, SD=1.32), even higher in the second block (Minimal Pair: mean=3.77, SD=0.97; Non-Minimal Pair: mean=3.50, SD=1.23). To test this hypothesis, we compared the results of the high-performance participants in experiment 1 (monolinguals) and the low-performance participants of experiment 2 (bilinguals). For each linguistic group, we used a median split to determine if each participant was a low or high performer. If in Experiment 2 the bilinguals reached a ceiling effect, the pattern of results of the bilingual low performers should be similar to the pattern of result of the monolingual high performers.

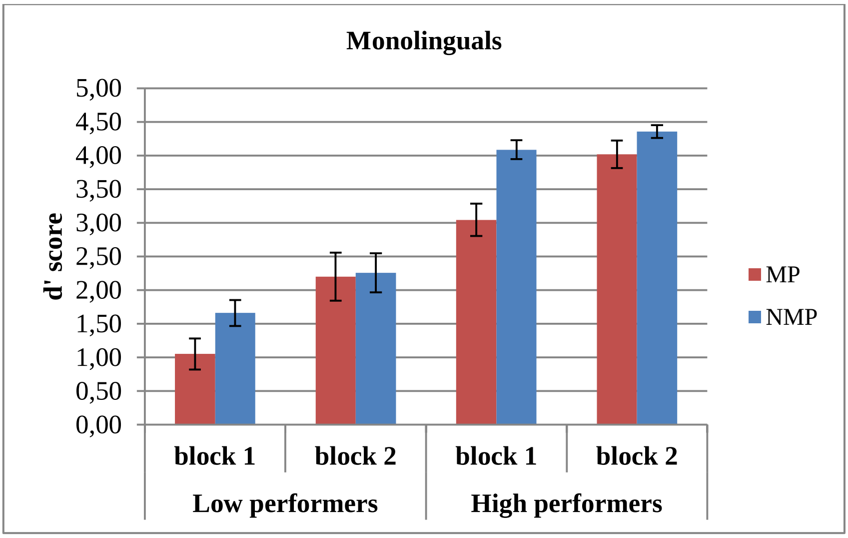
A 2 x 2 x 2 Performance (Bilingual Low vs. Monolingual High) x Condition (Minimal Pair vs. Non-Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed a showed a significant main effect of Block ($F(1, 44)=22.29$, $p<0.001$). This main effect of Block reflects higher mean d' scores in the second test block than in the first test block (3.53 vs. 2.79 respectively). The analysis also showed a significant main effect of Performance ($F(1, 44)=58.31$, p<0.001) indicating that the monolingual High performers performed better than the bilingual Low performers. Importantly, the analysis also showed a significant Condition by Performance interaction (F(1,44)=7.80, p=0.007) reflecting a larger increase in d' scores between the monolingual High and bilingual Low performers in the Non-Minimal Pair condition when compared to the Minimal Pair condition. Test of simple effects showed a significant effect of Condition for the monolingual High performers with the participants having significantly higher mean d' scores in the Non-Minimal Pair condition than in the Minimal Pair condition (t(22)= -3.86; p<0.001). There was no significant effect of Condition for the bilingual Low performers.

These results suggest that the monolingual High and bilingual Low performers have a different pattern of results indicating that the bilingual pattern of results in Experiment 2 does not reflect a ceiling effect but rather more a possible effect of bilingualism.

Results are shown in Figure 2.3.

Pooled analysis of Experiments 1 and 2

To check if monolingual and bilingual participants behaved in a different way we performed a pooled analysis of the results of both experiments. A 2 x 2 x 2 Language (Monolingual vs. Bilingual) x Condition (Minimal Pair vs. Non-Minimal Pair) x Block (1 vs. 2) mixed ANOVA was performed and yielded again a main effect of Block (F(1, 92)=41.77, p<0.001) reflecting higher mean d' scores in the second test block than in the first test block (3.42 vs. 2.71 respectively). The analysis also showed an almost significant main effect of Language ($F(1, 92)=3.91$, $p=0.051$) pointing in the direction that monolinguals and bilinguals behaved differently.



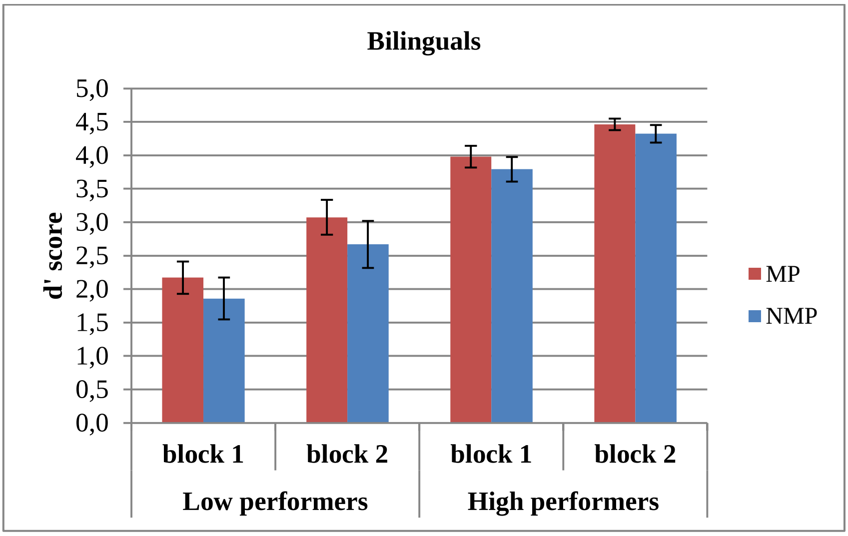


Figure 2.3 Mean d' scores and standard errors obtained by the Low and High performers in the Minimal Pair (MP, red) and Non-Minimal Pair (NMP, blue) conditions for the Monolingual (up) and Bilingual (bottom) participants.

Following Experiment 1, we analysed the results of Block 1 separately. A 2 x 2 Language (Monolingual vs. Bilingual) x Condition (Minimal Pair vs. Non-Minimal Pair) ANOVA was performed and yielded a marginal main effect of Language ($F(1, 92)=3.48$, $p=0.065$) indicating a tendency for bilinguals to perform better than monolinguals in this block. Importantly, the analysis showed a significant Language by Condition interaction ($F(1, 92)=4.21$, $p=0.043$) reflecting a larger difference in mean d' scores between the monolingual and bilingual participants in the Minimal Pair condition when compared to the Non-Minimal Pair condition. Test of simple effects showed a significant effect of language group in the Minimal Pair condition with the bilinguals having significantly higher mean d' scores than the monolinguals ($t(46)= -2.90$; $p=0.006$). There was no significant effect of language group in the Non-Minimal Pair condition.

Taken together, the results suggest that the pattern of results obtained in Experiment 2 is due to an effect of bilingualism. However, this effect was observed only in the Minimal Pair condition.

Spanish-Catalan bilinguals behaved differently from monolinguals. They did not seem to be sensitive to the type of familiarisation and showed good discrimination of the L2 contrast in both test blocks. Post-hoc analyses showed that this pattern of results is not reflecting a ceiling effect but rather more an effect of bilingualism allowing the bilinguals to discriminate the /ɒ/-/ʌ/ contrast better than the monolinguals. We elaborate the theoretical implications of the pattern of results obtained in the General Discussion section.

In order to confirm the exact role of the experimental condition on our participants' discrimination abilities, we assessed the baseline discrimination of both monolinguals and Spanish-Catalan bilinguals in a control study.

2.5 Experiment 3

The main goal of this control experiment was to assess if familiarization (Minimal Pair and Non-Minimal Pair conditions) enhanced or hindered participants' discrimination abilities. A significantly higher baseline discrimination in the control experiment than in the experimental conditions would suggest that familiarization hindered the discrimination. Conversely, a significantly lower baseline discrimination in the control experiment than in the experimental conditions would suggest that the familiarization facilitated the discrimination.

A second goal of the control experiment was to check if the simultaneous bilinguals already discriminate the L2 contrast better than the monolinguals, before the exposition to the familiarization. An additional group of native British English speakers was tested to better assess the discrimination of the /ɒ/-/ʌ/ contrast by our non-native participants.

2.5.1 Methods

Participants

Three groups of participants were tested for a total of 38 participants included in the analysis. An additional group of 8 participants (N= 4 monolinguals, N= 4 bilinguals) were tested but not included in the analysis because they did not reach the minimum number of valid trials in one of the conditions (see Results and Discussion section).

The first group of participants consisted in 16 Spanish (n=8) or Catalan (n=8) monolinguals (age range= 18-24 years old). The second group of participants consisted in 16 Spanish-Catalan simultaneous bilinguals (age range= 18-27 years old).

Participants were considered as monolingual if they have been exposed to only one language at home before 3 year of age and as bilinguals if they have been exposed to both languages from birth. They were students from the University Pompeu Fabra and were recruited by announcements through the university facilities.

The third group of participants consisted in 6 British English adult monolinguals (age range =21-28 years old). One participant was student at the University Pompeu Fabra while the others were recruited outside the University. Recruitment was done by announcements through social media and university facilities.

All participants reported no hearing problems. They were paid 10€/hour. The experiment was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). Written informed consent was obtained from the participants before the experiment was conducted.

On average, both monolingual and bilingual participants started learning English at school at the age of 5 years (Monolinguals: mean= 4.9 years, SD=1.5 years; Bilinguals: mean=4.5 years, SD=2.0 years). This is at an earlier age than the participants in Experiment 1 and 2. This difference was marginal for the monolingual participants ($p=0.08$) and significant for the bilingual participants (p=0.02). The details of the English scores for both linguistic groups are shown in Table 2.4.

Table 2.4. Detail of the English scores for the Monolinguals (up) and the Spanish-Catalan bilinguals (bottom). The questionnaire used a ten-point scale (1= very poor to 10= native proficiency).

Linguistic group	Variable	Minimum	Maximum	Mean	SD
Monolinguals	Onset of listening to English (years)	2	7	4.9	1.5
	Comprehension score (1-10)	6	10	8.5	1.2
	Reading score (1-10)	7	10	8.9	1.0
	Fluency score (1-10)	5	10	8.3	1.6
	Pronunciation score (1-10)	5	10	7.7	1.5
	Writing score (1-10)	6	10	8.6	1.4
Spanish-Catalan Bilinguals	Onset of listening to English (years)	1	8	4.5	2.0
	Comprehension score (1-10)	7	9	8.3	0.8
	Reading score (1-10)	6	10	8.4	1.0
	Fluency score (1-10)	4	9	7.3	1.2
	Pronunciation score (1-10)	4	10	7.2	1.2
	Writing score (1-10)	5	9	7.7	1.0

Stimuli, Apparatus and Procedure

They were the same as the previous experiments with the following exceptions.

Concerning the instructions, for the monolinguals and bilinguals, the text from the two previous experiments was kept and only the part concerning the familiarization phase was removed. For the English participants, the instructions were translated from Spanish to English.

Concerning the procedure, all participants completed the two test blocks of the original study, with no previous familiarization.

2.5.2 Results and Discussion

Analysis

The same pre-processing of the data as in Experiments 1 and 2 was done based on the reaction times. This resulted in the exclusion of one monolingual participant due to a too high number of trials excluded. An average of 12 trials (SD=1.89), 13 trials (SD=3.10) and 13 trials (SD=2.76) were discarded from the analysis for the Monolingual, Bilingual and English groups respectively. For all groups, this represents 5% of the total number of possible responses.

The d prime (d') score was calculated from the remaining responses for each contrast in each test block. Participants who did not obtain a mean d' score superior to 3 for the control contrast ("*bo*" vs. "*bu*") in the two test blocks were excluded from the analysis (Monolinguals: N=3; Bilinguals: N=3), as well as participants who obtained a score of 0 in each test block (Monolinguals: N=1). These numbers are similar to the number of participants discarded in the first two experiments.

As there was no familiarization before each test block, data was collapsed between blocks and analysed together. Results are presented in Figure 2.4.

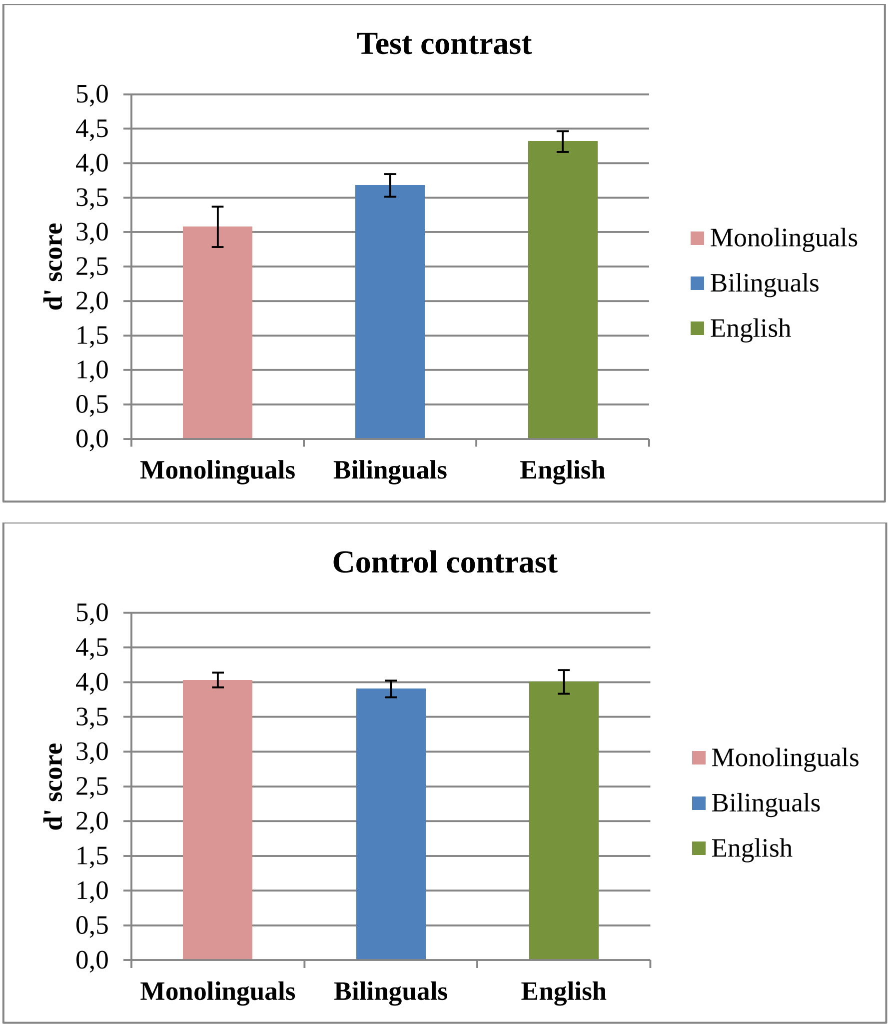


Figure 2.4 Mean d prime scores and standard errors for the test contrast (top) and control contrast (bottom) obtained by the Monolingual (pink), Bilingual (blue) and English (green) participants.

For the test contrast, the mean d’ score was 3.08 (SD=1.17) for the monolinguals, 3.68 (SD=0.65) for the simultaneous bilinguals and 4.31 (SD=0.37) for the British English participants.

For the control contrast, as expected, all three groups of participants scored very high: the mean d’ score was 4.03 (SD=0.42) for the monolinguals, 3.90 (SD=0.48) for the bilinguals and 4.00 (SD=0.42) for the English participants.

We first analysed the data of the control experiment to assess if the bilinguals had better baseline discrimination than the monolinguals. Results were also compared with the English participants to check if native speakers showed significantly better discrimination than our participants. A one-way between participants ANOVA showed a significant effect of language group on discrimination ($F(2, 35)= 4.65$, $p= 0.016$). Independent-samples t-tests (one-tailed) showed that the English participants had significantly higher mean d' scores than both the monolinguals ($t(20)=2.51$, $p=0.010$) and the bilinguals ($t(20)=2.24$, $p=0.018$). Moreover, bilinguals had significantly higher mean d' scores than the monolinguals ($t(30)=1.79$, $p=0.041$).
These results suggest that bilinguals discriminate the /ɒ-ʌ/ contrast better than the monolinguals. As expected, the discrimination of both our monolinguals and bilinguals remains imperfect when compared to the English participants.

We then assessed the exact role of the familiarization (Minimal Pair and Non-Minimal Pair) on our participants' discrimination abilities by comparing the results of the control experiment with the results of the block 1 in Experiment 1 and 2. As the results of Experiment 1 and 2 showed that monolinguals and bilinguals behaved differently to the familiarization, the data of each linguistic group was analysed separately.

For the monolinguals, results in Experiment 1 showed a better discrimination in the Non-Minimal Pair condition than in the Minimal Pair condition. Feldman et al. (2013) observed the same pattern with their participants and concluded that the Non-Minimal Pair condition facilitated the discrimination. We tested this hypothesis by comparing separately the mean d' score in the control experiment with the mean d' score in the Minimal Pair condition and in the Non-Minimal Pair condition. Independent two-samples t-tests showed that the mean d' score in the control experiment was significantly higher than the mean d' score in the Minimal Pair condition ($t(38)=2.56$, $p=0.015$) but not in the Non-Minimal Pair condition ($t<1$). This result suggests that for the monolinguals, the Minimal Pair condition hindered the discrimination while the Non-Minimal Pair does not seem to have had any impact.
For the bilinguals, results in Experiment 2 showed equivalent discrimination of the contrast in both experimental conditions. The results showed that the mean d' score in the control experiment was significantly higher than the mean d' score in the Non-Minimal Pair condition ($t(38)=2.40$, $p=0.022$ and marginally higher than the mean d' score in the Minimal Pair condition ($t(38)=1.89$, $p=0.067$). This result suggests that for the bilinguals, both familiarizations hindered discrimination (though for the Minimal Pair condition it was marginal).

Taken together, the results of the control experiment suggest that the bilinguals discriminate the L2 contrast better than the monolinguals without prior familiarization. Both monolinguals and bilinguals have an imperfect discrimination of the L2 contrast as compared to natives'.

Finally, different results were found concerning the roles of the experimental conditions on our participants' discrimination abilities. For the monolinguals, the Minimal Pair condition hindered the discrimination while the Non-Minimal Pair condition did not have any impact. For the bilinguals both experimental conditions seem to have hindered the discrimination.

2.6 General Discussion

The goal of this research was to investigate the effectiveness of word-level information not related to meaning when learning an L2 vocalic phonetic category. In Experiment 1, we found that Spanish and Catalan monolinguals were sensitive to word-level information as they tended to perceive the L2 contrast differently depending on the familiarization they were exposed to. In Experiment 2, simultaneous Spanish-Catalan bilinguals behaved differently from monolinguals and showed good discrimination regardless of the familiarization they were exposed to. The Experiment 3 evaluated the baseline discrimination of the L2 contrast for both monolinguals and bilinguals and showed that simultaneous bilinguals discriminated the contrast better than the monolinguals without prior familiarization. Moreover, when assessing the exact role of the experimental conditions on our participants' discrimination abilities, results showed that for the monolinguals only the Minimal Pair condition had an impact and hindered discrimination. For the bilinguals, the Non-Minimal hindered discrimination while the Minimal Pair only showed a tendency to hinder it.

In Experiment 1, we tested how word-level information may influence Spanish and Catalan monolinguals in perceiving an L2 vocalic contrast using a phonetic learning task. In the first test block, participants familiarized with the Non-Minimal Pair condition categorized the sounds they heard as belonging to two different categories more often than the participants familiarized with the Minimal Pair condition. This is a replication of the pattern found by Feldman et al. (2013) who tested American English participants on their discrimination of a native overlapping vocalic contrast.

As previously discussed, the effects were observed in the first test block instead of the second test block. This may be due to our L2 contrast being easier to discriminate than the native contrast used by Feldman et al. (2013). Even if previous studies suggested that Spanish monolinguals had difficulties in discriminating the /ɒ/-/ʌ/ contrast (Escudero & Chládková, 2010) it was not among the most difficult ones. The choice of an easier contrast was done because we were concerned that the short familiarization might not be long enough to elicit any improvement. Considering that Feldman et al. (2013) tested a native contrast, our selection seemed a priori justified. It would be interesting to assess the discrimination of a more difficult L2 contrast such as the British English contrast /æ/-/ʌ/ (Escudero & Chládková, 2010) to verify if the effect we observed is a robust one. Another interesting contrast to test with our current population would be a difficult L2 contrast already present in the bilinguals' second language such as the Catalan /e-ɛ/ contrast for Spanish-dominant Spanish-Catalan bilinguals. Several studies with early Spanish-Catalan bilinguals, raised as monolingual Spanish but exposed to Catalan from around 3 years old at school, have shown their systematic difficulties to discriminate the /e-ɛ/ contrast (Pallier, Bosch & Sebastián-Gallés, 1997; Sebastián-Gallés & Soto-Faraco, 1999; Pallier, Colome & Sebastian-Galles, 2001; Bosch, Costa & Sebastián-Gallés, 2000; Sebastián-Gallés, Echeverria & Bosch, 2005). These results suggest that even early and extensive daily exposure to a second language is not sufficient for listeners to acquire specific contrasts in their second language. If the results with the Spanish dominant bilinguals replicate the pattern found in Experiment 1, it would add to the evidences suggesting that the changes induced by bilingual exposure take place very early in life.

As we briefly reviewed, the principal models on L2 sound learning (SLM, PAM and L2LP) consider the relative distribution of the L1 and L2 phonemes in the acoustic space as predictors of how a L2 sound will be perceived. The acoustic distribution of the /ɒ/ and /ʌ/ sounds is ambiguous with regards to both the Spanish and Catalan vocalic repertoires suggesting two possible scenarios with opposite predictions. The first scenario would be that the acoustic distribution of the /ɒ/ and /ʌ/ sounds is close to both Catalan and Spanish single L1 category /a/. This is similar to the Single Category assimilation (PAM) and New scenario (L2LP) predicting particular difficulties to learn the contrast. The second scenario would be that the acoustic distribution of the /ɒ/ and /ʌ/ sounds is close to the Spanish and Catalan L1 categories /a/ and /o/. This is similar to the Two-Category assimilation (PAM) and Similar scenario (L2LP) predicting a good discrimination of the contrast. For both scenarios, the difference in number of vowels in the Catalan and Spanish vocalic repertoires (8 versus 5 respectively) should not influence the results. Accordingly, in Experiment 1 both Catalan and Spanish participants should show either a bad discrimination (following the first scenario) or a good discrimination (following the second scenario) of the /ɒ/-/ʌ/ contrast in both experimental condition. However, the participants in the Non-Minimal Pair condition tended to discriminate the contrast better than the participants in the Minimal Pair condition. This result suggests that our participants were sensitive to the different word contexts present in the experimental conditions and that top-down information influenced the way they perceived the /ɒ/-/ʌ/ contrast. Importantly, the pattern of results was similar between the Catalan and Spanish participants confirming that the number of vowels does not influence the way L2 sounds are perceived.

Crucially in our study (and as in Feldman et al. (2013)), information about meaning was not provided. According to the PAM and the L2LP (revised), it is precisely the use of meaning from the lexicon (PAM) or the minimal pairs (L2LP) that may help separate phonemes. Our pattern of results thus suggests that top-down information not related to meaning can also constrain the perception of an L2 contrast. Moreover, the tendency of our participants to better discriminate the contrast in the Non-Minimal Pair condition also suggests that when meaning is not available, minimal pairs seem to be less efficient than non-minimal pairs to help separate close sounds. This is not in line with the predictions of the L2LP (revised) that minimal pairs when meaning is available may facilitate discrimination.

Altogether the results of Experiment 1 replicate the pattern found by Feldman et al. (2013) with an L1 contrast and extend the influence of word-level information not related to meaning to the case of an L2 contrast.

In Experiment 2, we tested the hypothesis that bilingualism may have an impact on the use of word-level information and tested Spanish-Catalan bilinguals with the same phonetic category learning task. Simultaneous bilinguals showed a very good discrimination of the contrast in both test blocks regardless of the experimental condition. Further analysis suggested a different pattern between the high-performance participants in Experiment 1 (monolinguals) and low-performance participants in Experiment 2 (bilinguals) indicating that the simultaneous bilinguals in Experiment 2 did not show a ceiling effect. The pooled analysis of the monolingual and bilingual data suggested an effect of bilingualism in the first test block but only for the Minimal Pair condition. In this condition, bilinguals discriminated the contrast significantly better than the monolinguals.

Thus, the simultaneous bilinguals behaved differently from the monolinguals and showed a different pattern of results. Crucially here, it is important to note that the majority of the monolingual participants in Experiment 1 were actually highly-skilled early bilinguals (Minimal Pair condition: 22 over 24 participants; Non-Minimal Pair condition: 21 over 24 participants). They were raised as monolinguals (Spanish or Catalan) at home but have learned their second language very early in life, around 3-4 years old. Moreover, in most of the cities in Catalonia both Spanish and Catalan are used by the vast majority of the population on a daily basis. Our monolingual participants would have been categorized as bilinguals in many linguistic investigations. The fact that the simultaneous bilinguals in Experiment 2 behaved differently from the monolinguals/early bilinguals in Experiment 1 points in the direction of changes induced by bilingual exposure taking place very early in life.

The investigation of bilingual language acquisition in infants remains scarce. To our knowledge, the only model proposed for infant bilingual language acquisition is the PRIMIR (Processing Rich Information from Multidimensional Interactive Representations) model by Curtin, Byers-Heinlein and Werker (2011). Importantly, PRIMIR makes the same predictions for monolingual and bilingual infants when accounting for the acquisition of the phonetic categories. Accordingly, in Experiment 2 Spanish-Catalan bilinguals should show a similar pattern to the monolinguals. However, bilinguals showed a good discrimination in both experimental conditions.

This good discrimination could be due to the bilinguals’ increased sensitivity to small sub-phonemic/acoustic information. As previously reviewed, this sensitivity has been reported in both infant and adult bilinguals in word identification tasks (Mattock, Polka et al. 2010; Fennell & Byers-Heinlein, 2014; Ju & Luce, 2004). Similar sensitivity was also found in perception tasks. When assessing the perception of natural /ba/-/pa/ syllables varying in VOT (voice onset time) Elman, Diehl and Buchwald (1977) found that Spanish-English bilinguals showed evidence of a phoneme boundary shift depending on the language used to present the stimuli. When presented in English the syllables were identified significantly more often as /ba/ while when presented in Spanish the same stimuli were identified significantly more often as /pa/. These results suggest that Spanish-English bilinguals are using separate voice-voiceless prototypes for each language. Similarly, research with French-English bilingual infants showed that they can discriminate tokens of the /b/-/p/ continuum across both English and French boundaries (Burns, Yoshida, Hill & Werker, 2007) and that they can discriminate between the two cross-linguistic realizations of the same phoneme /d/ (dental in French vs. alveolar in English; Sundara, Polka & Molnar, 2008). This sensitivity to small sub-phonemic/acoustic information may have been a mechanism used by the simultaneous bilinguals to help separate their two languages and build appropriate phonetic representations in each of their language. In our experiment, simultaneous bilinguals may have detected more easily the acoustic differences between the tokens allowing them to better discriminate the contrast.

Spanish-Catalan bilinguals not only showed good discrimination of the /ɒ/-/ʌ/ contrast but they were also significantly better than the monolinguals in the Minimal Pair condition. One possible explanation for this result is that Spanish-Catalan bilinguals may pay more attention to word context information. Since birth, simultaneous Spanish-Catalan bilinguals have been exposed to two typologically close languages that share a high amount of cognate words among their translation equivalents. These cognates differing mainly on their vocalic sounds, Spanish-Catalan bilinguals have been daily exposed to a speech stream presenting a high vocalic variability, increasing the number of minimal pairs. The attention to word context information would have helped Spanish-Catalan bilinguals to acquire their vocalic categories. This may have favoured the bilinguals in the Minimal Pair condition when compared to the monolinguals. However, it cannot be excluded that this pattern of results may be simply due to bilingual exposure in general. This possibility could be explored by testing a bilingual population exposed to distant languages such as Spanish and Basque. As they do not share the same etymological origin, the number of cognates (and by extension minimal pairs) in the Spanish-Basque speech stream is very limited. If bilingual exposure only is sufficient to increase sensitivity to word context, Spanish-Basque bilinguals should display the same pattern of results as the Spanish-Catalan bilinguals. Conversely, if the sensitivity to word context is related to the high amount of minimal pairs in the speech stream, Spanish-Basque bilinguals should display the same pattern of results as our monolingual participants.

The absence of differences between the two experimental conditions for the simultaneous bilinguals was a rather unexpected result. One possible explanation is that because we used naturally produced tokens, subtle sub-phonemic differences were likely to be present within the same category of syllables. If simultaneous bilinguals were more sensitive to sub-phonemic information, it might be possible that while monolinguals encoded the different tokens of each syllable as equivalent, simultaneous bilinguals encoded them as different. Therefore, the Non-Minimal Pair condition would become more similar to the Minimal Pair condition for the simultaneous bilinguals when compared to the monolinguals. In the Non-Minimal Pair condition, monolinguals would indeed treat all different */tʰɒ/* syllables as exemplars of the same category by discarding small within-class variations. On the other hand, simultaneous bilinguals would treat the different */tʰɒ/* syllables as different exemplars (at least to a certain extent). The different */tʰɒ/* syllables would be stored as */tʰɒ/*1, */tʰɒ/*2, */tʰɒ/*3 etc. consequently reducing the differences between the two experimental conditions. This very tentative explanation remains speculative, and it will require additional evidence, like, for instance, performing some computational modelling. Taken together, the results in Experiment 1 and 2 suggest lifelong impact of simultaneous bilingualism on the use of word-level information.

In experiment 3, we assessed the baseline discrimination of the L2 contrast of our participants by testing them with the same phonetic category learning task without previous familiarization. Native British-English participants were also tested to compare our participants' discrimination to the one of native speakers. As expected, English participants showed better baseline discrimination than both monolinguals and bilinguals. Importantly, bilinguals also showed better baseline discrimination than the monolinguals indicating an increased sensitivity to sub-phonemic/acoustic information.

Experiment 3 also allowed us to evaluate the exact role of the experimental conditions on our participants' performances by separately comparing for each linguistic group the baseline discrimination score with the discrimination score in the Minimal Pair and Non-Minimal Pair conditions.

For the monolinguals, the baseline discrimination score was higher than the discrimination score in the Minimal Pair condition but was not different from the discrimination score in the Non-Minimal Pair condition. This result indicates that the effect of familiarization was restricted to the Minimal Pair condition, and that this condition hindered our participants' performance. Feldman et al. (2013) proposed that the Non-Minimal Pair condition facilitates discrimination by providing a clearer word context. However, our results do not exactly contradict this hypothesis. As previously said, we used an easier contrast than Feldman et al. (2013). In this case, the Non-Minimal Pair condition may not have been very informative for our participants to separate sounds they already discriminate quite well. On the other hand, the Minimal Pair condition by informing that two sounds may belong to the same category hindered discrimination. The reverse pattern may have occurred for Feldman et al.'s (2013) participants: while the Non-Minimal Pair condition was informative and helped them separate the sounds, the Minimal Pair condition may not had any impact as the contrast was already too difficult to discriminate. Taken together, these results suggest that both the Minimal Pair and Non-Minimal Pair condition influence the way listeners perceive L1 and L2 sounds, their actual role depending on the initial difficulty to discriminate the contrast.

As previously reviewed, minimal pairs have been extensively used as training stimuli to teach L2 contrasts. The rationale was that the different meaning of each pair word will serve as an additional force to separate close/overlapping sounds. However, our results indicate that when meaning is not available, exposure to sounds appearing in similar word contexts (just as minimal pairs do) hinders discrimination, at least in the case of an easy L2 contrast. Future investigations of new L2 contrast teaching may consider the use of minimal pairs more cautiously. It would also be interesting to investigate if training without meaning may help adult listeners mastering a difficult L2 contrast that could not be acquired with training based on the use of minimal pairs.

For the Spanish-Catalan bilinguals, there was a trend that the Minimal Pair condition also hindered performance. Critically, the baseline discrimination score was significantly higher than the discrimination score in the Non-Minimal Pair condition indicating that this condition hindered performance too. Thus, for the simultaneous bilinguals, the effect of the familiarization is always the same, it hinders. This was an unexpected result as in Experiment 2, simultaneous bilinguals showed good discrimination scores in both experimental conditions. One possibility is that the bilinguals' baseline discrimination was very high and that the observed differences may be spurious. New investigations with lower baseline discrimination L2 contrasts may shed some light on this puzzling result.

The results of the present research replicate the results found by Feldman et al. (2013) and extend the influence of word-level information not related to meaning to the case of an L2 vocalic contrast. These results also argue for more interactive accounts of L2 learning where the influence of the lexicon would be considered through meaning as well as through word forms as L2 learners may not always have access to meaning or referents.

We also provide evidence that simultaneous bilingual exposure had an influence on the use of word-level information. However, the exact mechanism behind this pattern remains unclear. Future research is also needed to clarify if the divergent results found with our bilingual participants are due to bilingual exposure in general or is specific to our Spanish-Catalan population.

3. EXPERIMENTAL SECTION 2

COMPARING MONOLINGUALS AND BILINGUALS LEARNING A NON-NATIVE PHONEME CONTRAST: INFANCY

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3.1 Abstract

The identification of the mechanisms allowing the perception of native and non-native sounds remains a central subject of research in infant language acquisition. Feldman et al. (2013) investigated possible top-down influences on the learning of a native vocalic contrast and showed that, contrary to the assumption that meaning is required to constrain phonetic learning through minimal pairs, 8 month-olds monolingual infants are sensitive to word-level information not related to meaning. Here, we investigated if 8 month-old monolinguals are also sensitive to word-level information when learning a non-native contrast and if simultaneous bilingual exposure may already have an impact on the way such information is used. We adapted the study by Feldman et al. (2013) and tested monolingual and bilingual 8 month-old infants on their perception of a non-native vocalic contrast after familiarization with pseudo-words including minimal pairs or not. Our results did not show any effect of type of familiarization for both monolinguals

and bilinguals. However, both populations showed contrastive patterns: monolinguals discriminated the contrast but bilinguals did not. These results suggest that at 8 month-olds, infants are not sensitive to word-level information when learning a non-native vocalic contrast and that bilingual exposure did not have any influence on the use of word-level information but rather on the discrimination abilities.

3.2 Introduction

When learning their native language(s), one of the first challenge infants are faced with is the establishment of the phonetic categories. At birth, infants can discriminate phonetic contrasts from almost all the world's languages (Eimas et al., 1971). Between 6 and 12 months, the infant speech perception system specializes towards the phonemic contrasts belonging to the language(s) present in their direct environment. During this perceptual reorganization process, infants lose their sensitivity towards non-native contrasts while their discrimination for the native ones increases (Kuhl et al., 2006; Narayan, Werker & Beddor, 2010). This process takes place earlier for the vowels (6 months, Kuhl et al., 1992; Polka & Werker, 1994) than for the consonants (10-12 months at the earliest for the plosives, Werker & Tees, 1984). Accounts for this reorganization process include the role of biological factors (see Werker & Hensch, 2015 for a modern conceptualization of critical periods) as well as environmental factors (mostly bottom-up) such as language exposure. Two different types of mechanisms have been proposed to account for the establishment of the phonetic categories: those relying on bottom-up information and those relying on top-down information.

Perhaps the most popular bottom-up mechanism to explain the emergence of phonemes is the distributional learning account (Maye & Gerken, 2000; Maye, Werker & Gerken, 2002). According to this account, learners form phonetic categories by tracking the distribution of sounds within the acoustic space. Exposure to a bimodal distribution of sounds would lead to the formation of two categories while exposure to a unimodal distribution would lead to the formation of a unique category. Maye and colleagues showed that both adults and infants are sensitive to distributional information. They tested their participants on their discrimination of the native English voiced [d] (as in **d**ay) and voiceless unaspirated [t] (as in s**t**ay). Importantly, both sounds are not contrastive in English and can be perceived as members of the same category [d]. Participants were first familiarized with a continuum of synthesized [da]-[ta] tokens running from [d] to [t]. All participants heard the same tokens but according to different statistical distributions. The unimodal distribution group heard four times more phonemes from the center of the continuum while the bimodal distribution group heard four times more phonemes from the two endpoints of the continuum. When asked to assign pairs of endpoint [da]-[ta] tokens into one or two categories, adult participants in the bimodal distribution group were more likely to categorize the sounds in two different categories than the participants in the unimodal distribution group. Crucially, a similar pattern of results was found when testing 6 and 8 month-olds with the preferential looking procedure. Only the infants familiarized with the bimodal distribution displayed evidence of discriminating the endpoint [da]-[ta] stimuli (Maye, Werker & Gerken, 2002; see Maye, Weiss & Aslin, 2008 for a more difficult contrast).

These results suggest that both adults and infants are sensitive to distributional information and are able to use it to form new categories. However, one limit for distributional learning would be two sound categories presenting a high degree of overlapping in the acoustic space. In this case, the overlapping distribution may mislead the learner into creating a unique category.

On top of the bottom-up distributional learning process, top-down mechanisms have also been proposed to play a significant role in establishing phonetic categories. This proposal considers that infants start to learn their first words around the same period as the perceptual reorganization starts (around 6 months, Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999).

Models of infant native language acquisition such as PRIMIR (Werker & Curtin, 2005) proposed that the lexicon influences phonetic learning by providing semantic information. Indeed, PRIMIR (Processing Rich Information from Multidimensional Interactive Representations) is an interactive framework allowing bidirectional influences between the infants' perceptual system and the emergent lexicon. Possible top-down influences from the lexicon may occur during perceptual learning as the need to improve their lexical representations may help the infants consolidate their phonetic categories. In other words, word meaning is considered as a driving force during phonetic learning. This is line with the role proposed in theoretical linguistics for the minimal pairs in phonetic learning. Minimal pairs (words differing in a single sound with a different meaning, such as ‘road’ and ‘load’) have been proposed to play a major role in the establishment of the phonetic categories. For example, the discovery that ship, containing the sound /ɪ/, and sheep, containing the sound /iː/, have different meaning would lead learners to consider that the sounds /ɪ/ and /iː/ are contrastive and form two categories. However, this rationale also supposes an extensive knowledge of word meanings. Without this knowledge, members of a minimal pair may be considered as two possible forms of the same word. Infants know fewer minimal pairs than their adult peers (Caselli, Bates, Casadio, Fenson, Fenson, Sanderl & Weir 1995), and even less during the first year of life. Thus, the actual role of the minimal pairs and meaning may be limited in early infancy.

Recently, the use of the word context in which speech sounds occur has also been suggested to influence how phonetic sounds are perceived (Thiessen, 2007; Swingley, 2009; Feldman, Myers, White, Griffiths & Morgan, 2013a; Feldman, Griffiths, Goldwater & Morgan, 2013b). As previously said, in the case of overlapping categories distributional learning may mislead learners into forming a unique category. Despite an overlapping distribution (for example /iː -ɪ/ in English), each sound of the two categories is usually heard in different word contexts (non-minimal pairs) such as ‘treat’ for the sound /iː/ and ship for the sound /ɪ/. As a matter of fact, minimal pairs (e.g sheep/ship) constitute a minority of the contexts in which two phonemes appear in the speech stream. The clear different word forms of ‘treat’ and ‘ship’ are possible additional word-level cues to inform learners to separate the /iː/-/ɪ/ phonetic categories. Importantly here, this proposal implies that learners can acquire sounds *without* meaning or referents. Consequently, exposure to sounds appearing in similar word contexts (or minimal pairs, e.g ship/sheep) would hinder discrimination by informing learners that these sounds may belong to the same category while the exposure to sounds appearing in very dissimilar word contexts (or non-minimal pairs, e.g treat/ship) would facilitate discrimination. This lead Feldman et al. (2013a) to propose that the non-minimal pairs present in the speech stream may help infants separate overlapping categories by providing distinct word contexts for similar sounds before meaning is available.

Feldman, Myers, White, Griffiths and Morgan (2013a) tested this hypothesis and assessed the possible influence of word contexts on the perception of a vocalic contrast. They tested both American English adults and 8 month-old infants on their discrimination of the native overlapping vocalic contrast /ɑ/-/ɔ/. They used synthesized stimuli forming a continuum from /ɑ/ (*ah*) to /ɔ/ (*aw*) and embedded them in disyllabic pseudo-words: /lit^{h}**ɑ**/-/lit^{h}**ɔ**/ and /gut^{h}**ɑ**/-/gut^{h}**ɔ**/. These pseudo-words were used to create two word-context conditions: the Minimal Pair condition, where the vocalic contrast appeared in all the pseudo-words (/lit^{h}**ɑ**/, /lit^{h}**ɔ**/, /gut^{h}**ɑ**/, /gut^{h}**ɔ**/) and the Non-Minimal Pair condition where the contrast appeared in distinct word-context (/litʰ**ɑ**/-/gutʰ**ɔ**/ <u>or</u> /litʰ**ɔ**/-/gutʰ**ɑ**/). In each condition, the syllables *li* and *gu* served as word context cues that could indicate that the /tʰ**ɑ/** and /tʰ**ɔ**/sounds belong to one or two categories. The Minimal Pair condition presented the /ɑ/-/ɔ/ vowels interchangeably with the syllables *gu* and *li*, possibly indicating that the two sounds may belong to the same category. The Non-Minimal Pair condition was divided into two sub-conditions: half of the participants heard the vowel /ɑ/ only with the syllable *li* and the vowel /ɔ/ only with the syllable *gu* while the other half of the participants heard the vowel /ɑ/ only with the syllable *gu* and the vowel /ɔ/ only with the syllable *li*. Feldman et al. hypothesized that the clearer word context given by the Non-Minimal Pair condition would help their participants, both adults and infants, separating the overlapping /ɑ/-/ɔ/ vowels.

Adult participants were first tested with a phonetic category learning task and completed two identical familiarization-testing blocks. After being passively familiarized according to one of the two word-context conditions, participants were tested on their discrimination of the test syllables /tʰɑ/ vs. /tʰɔ/. Results in the second test block showed that participants familiarized with the Non-Minimal Pair condition assigned the test syllables to different categories significantly more often than the participants familiarized with the Minimal Pair condition.

Importantly for our present research, similar results were found in 8 month-olds with a Head-turn Preference Procedure. As their adult peers, infants were first familiarized according to either the Minimal Pair or the Non-Minimal Pair conditions. Discrimination of the /ɑ/-

/ɔ/ contrast was then assessed by measuring the mean looking times towards two types of test trials: *Non-Alternating* trials containing the test syllables repeating one of the two test vowels (e.g: /t^{h}**ɑ**/-/t^{h}**ɑ**/-/t^{h}**ɑ**/-/t^{h}**ɑ**/… or /t^{h}**ɔ**/-/t^{h}**ɔ**/-/t^{h}**ɔ**/-/t^{h}**ɔ**/…), and *Alternating* trials containing test syllables alternating the two test vowels (e.g: /t^{h}**ɑ**/-/t^{h}**ɔ**/-/t^{h}**ɑ**/-/t^{h}**ɔ**/…). Results showed that only the infants familiarized with the Non-Minimal Pair condition discriminated the contrast as they looked significantly longer to the Non-Alternating trials than to the Alternating trials.

Altogether, the authors concluded that adults as well as 8 month-olds are sensitive to word-level information not related to meaning and that this information can constrain the way they categorize native sounds. However, the possible influence of such information has not been investigated yet in the case of a non-native contrast.

In the present research, following Feldman et al. (2013a) we want to address if 8 month-old monolingual infants are also sensitive to word-level information, here when learning a non-native contrast phonetic category. We also want to assess if as early as 8 month-olds, bilingual exposure may already have an impact on the way word-level information is used.

Since birth, bilingual infants have been exposed to two phonemic repertoires that overlap to different degrees depending on the languages they are exposed to. The few studies (mainly behavioral) that have addressed the perceptual reorganization in bilinguals have shown that they acquire their native phonetic categories at the same age as the monolinguals. These results were found for both consonants (Burns, Yoshida, Hill & Werker, 2007; Sundara, Polka & Molnar, 2008) and vowels (Albareda-Castellot, Pons & Sebastian-Galles, 2011). However, results of recent studies measuring brain responses (ERPs/EEG) showing less robust responses for native phonemes in bilinguals when compared to monolinguals also point in the direction of a more complex process (Garcia-Sierra et al., 2011). Despite these divergent results, up until now, no major differences have been found between monolinguals and bilinguals concerning the establishment of the phonetic categories. Similarly, no differences have been reported between monolinguals and bilinguals in the case of later language acquisition processes such as phonotactics (Sebastián-Gallés & Bosch, 2002) and word acquisition (Hoff et al., 2012; Hoff, Rumiche, Burridge, Ribot & Welsh, 2014).

To our knowledge, only one model has been proposed to account for the bilingual perceptual reorganization process: the PRIMIR model by Curtin, Byers-Heinlein and Werker (2011). Originally developed to account for monolingual language acquisition it has been extended to encompass bilingual acquisition. As previously said, PRIMIR is a highly interactive framework with bidirectional influences between its components. Importantly, PRIMIR considers that bilingual infants possess the same framework as the monolinguals, framework that enables them to separate their two languages. As a consequence, bilingual infants acquire the phonetic categories in each of their language at the same age as their monolingual peers as just reviewed. Although the details of the mechanism underlying bilinguals' learning of the phonetic repertoires remains unclear , it is mainly based on the use of the same bottom-up distributional learning mechanism as the monolinguals. As for the monolinguals, top-down influences by the lexicon and the use of meaning may occur during phonetic learning. In light of PRIMIR, bilinguals should not differ from their monolingual peers when learning and perceiving native and non-native contrasts.

However, the linguistic environment bilinguals are exposed to may have influenced how they treat sounds. Infants growing up in a bilingual environment are exposed to more variability in the speech stream than monolinguals. They are more exposed to accented speech as their parents/caregivers may also be themselves bilinguals with unequal proficiency in one of their two languages. Moreover, unlike monolinguals, bilinguals also constantly need to identify the language they are addressed with. As a consequence, bilinguals may have learned to pay more attention to sub-phonemic/acoustic information. Research has shown that both monolingual and bilingual infants are sensitive to such information in task related to word identification (Mattock, Polka et al., 2010; Fennell & Byers-Heinlein, 2014). Using the Switch task, Mattock and colleagues tested 17 month-olds, both monolinguals (French or English) and French-English bilinguals on their discrimination of the /b-g/ contrast, phonemic in both languages. In a typical switch task, infants are first taught two word-object pairings (e.g, “bos” with object A, “gos” with object B) and then tested by presenting them pairings maintaining the word-object link (Same trials) and pairings violating this link (e.g, “bos” with object B, Switch trial). Significant higher looking times for the Switch trials are taken as evidence that infants detected the switch and discriminated the contrast. Importantly, in their study, Mattock and colleagues used different audio tokens in which the /g/ and /b/ sounds were pronounced either with an English or French pronunciation or with an intermediate pronunciation between French and English. Results showed that each linguistic group detected the switch only when tested with the audio tokens corresponding to the language input in their real environment. Still with the Switch task, Fennell and Byers-Heinlein (2014) found similar results when manipulating the language context of the word-object pairings presentation. When tested on their discrimination of the /k-g/ contrast, 17 month-old English monolinguals and French-English bilinguals detected the switch only when the word-object pairing was taught by a speaker matching their linguistic environment. These results point in the direction of increased sub-phonemic/acoustic sensitivity in bilingual infants when acquiring their native phonetic categories and during word learning. Such increased sensitivity may favor the learning of a new phonemic contrast. As previously said, the bilingual environment may have prompted bilingual infants to pay more attention to such information, favoring them when learning a new phonemic contrast.

Moreover, in the Chapter 2, we investigated the influence of word-level information in adults learning a second language (L2) contrast. Our results showed that simultaneous bilinguals (corresponding here to our bilingual infants) were better at discriminating a non-native contrast and were less sensitive to word-level information. Following these results, we expect to find differences between bilingual and monolingual infants in the effects of exposure to phonetic contrasts appearing in minimal or non-minimal pairs.

We adapted the infant study by Feldman et al. (2013a) and tested both monolingual (Spanish or Catalan) and bilingual (Spanish-Catalan) 8 month-olds on their discrimination of a non-native vocalic contrast, the British English /ɒ/-/ʌ/ contrast. These two vowels do not exist in Spanish or Catalan. Difficulties in discriminating the /ɒ/-/ʌ/ contrast have been reported for adult Spanish and Italian native participants (Escudero & Chládková, 2010; Flege & MacKay, 2004). Given that the Italian and Catalan vocalic repertoires are similar and that the Spanish repertoire contains even less vowels than the Catalan one, one may assume the /ɒ/-/ʌ/ contrast as difficult to learn by Spanish and Catalan natives. Contrary to the original study, as the contrast was non-native for our participants and to approach natural learning environments, we used naturally produced tokens instead of synthesized tokens with a vocalic continuum. The same corpus of disyllabic non-words (*/lit*ʰ***ɒ****/-/lit*ʰ***ʌ****/* and */nut*ʰ***ɒ****/-/nut*ʰ***ʌ***/) as in the adult study in Chapter 2 has been used. Using the Head-Turn Preference procedure, infants were familiarized according to one of two word-context conditions: the Minimal Pair condition where the vocalic contrast appeared in all the non-words (e.g*, /lit*ʰ***ɒ****/, /nut*ʰ***ɒ****/, /lit*ʰ***ʌ****/, /nut*ʰ***ʌ***/) and the Non-Minimal Pair condition where the contrast appeared in distinct word context (e.g, */lit*ʰ***ɒ****/-/nut*ʰ***ʌ***/* or */lit*ʰ***ʌ****/-/nut*ʰ***ɒ****/*). Infants were then tested on their discrimination of two types of trials: *Non-Alternating* trials containing the test syllables repeating one of the two test vowels (e.g: "/tʰ**ɒ**/-/tʰ**ɒ**/-/tʰ**ɒ**/-/tʰ**ɒ**/…" or "/tʰ**ʌ**/ -/tʰ**ʌ**/-/tʰ**ʌ**/-/tʰ**ʌ**/"), and *Alternating* trials containing test syllables alternating the two test vowels (e.g: "/tʰ**ɒ**/-/tʰ**ʌ**/-/tʰ**ɒ**/-/tʰ**ʌ**/…"). The syllables *nu* and *li* served as word context that could inform the infants whether the /tʰɒ/ and /tʰʌ/ syllables belonged to one or two categories. Discrimination of the contrast will be indicated by a significant difference in looking times for each type of test trials.

Two experiments were implemented. In the first experiment, we investigated if word-level information can influence how Spanish and Catalan monolingual 8 month-olds perceive a non-native vocalic contrast. We expected to replicate the pattern found by Feldman et al. (2013a) with the 8 month-olds discriminating the contrast only in the Non-Minimal Pair condition. Given the good discrimination of the contrast by the monolingual adults in the previous chapter, it is also possible that 8 month-olds will discriminate the contrast in both conditions but still with a better discrimination in the Non-Minimal Pair condition.

In the second experiment, we tested Spanish-Catalan bilinguals with the same paradigm to evaluate the possible early impact of bilingualism on the use of word-level information. As bilingual exposure may have increased bilinguals' sensitivity to sub-phonemic information, we expected them to behave differently from the monolinguals and to show better discrimination than the monolinguals in both experimental conditions. Moreover, given the lower sensitivity to word-level information of the adult simultaneous bilinguals in the previous chapter, we expected the bilingual infants to discriminate the contrast similarly in both experimental conditions.

3.3 Experiment 1

In this experiment we tested if, as their adult peers, 8 month-old monolingual infants are sensitive to word-level information not related to meaning when learning a non-native contrast.

3.3.1 Methods

Participants

A total of forty-eight 8 month-old infants were tested and included in the analysis. The infants were either Catalan or Spanish monolinguals (Catalan (N=27), Spanish (N=21); 25 boys, age range=237-271 days, mean=256 days). Fourteen additional infants were tested but not included in the final analysis due to: experimenter's error or technical issue (N=5), crying and fussiness (N=5), looking time outlier (N=1, see Results and Discussion section), and parental interference (N=3). An additional group of 19 infants has been also tested but excluded from the analysis due to an experimental error linked to the camera computer screen used for the online coding.

Participants were recruited by visiting maternity rooms at the Hospital Quirón and the Clínica Sagrada Familia in Barcelona, Spain. All participants were healthy, full-term infants (> 37 GW) and had no known hearing deficits.

A linguistic questionnaire (adapted from Bosch & Sebastián-Gallés, 2001) was administered to determine infants' language background and familiarity. Participants were exposed to Catalan or Spanish at least 90% of the time.

The research was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). Written informed consent was obtained from the participants' caregiver before the experiment was conducted.

Stimuli

This experiment used the same auditory stimuli as in Chapter 2 with the adult participants. They consisted in the same four naturally-produced exemplars of each filler syllables *li* and *nu* and each test syllables /tʰɒ/ and /tʰʌ/.

For the familiarization, the same 4 test pseudo-words (*/litʰɒ/, /litʰʌ/,* /*nutʰɒ/ and /nut*ʰʌ/) were constructed by concatenating the test and filler syllables. Sixteen exemplars of each /*litʰɒ/, /litʰʌ/,* /*nutʰɒ/ and /nut*ʰʌ/ pseudo-words were created by combining the four tokens of *nu* or *li* with each of the four /tʰɒ/ and /tʰʌ/ test syllables. In total, 64 disyllabic pseudo-words were created. Contrary to the adult experiment, there were no filler words.

Using the Audacity software, the pseudo-words were used to create three familiarization strings corresponding to each experimental condition (one string for the Minimal Pair condition and two strings for the Non-Minimal Pair condition). Each string contained 128 tokens separated by a 500-ms interstimulus and lasted 2 minutes and a half (for the details of each string, see the Procedure section below).

For the test phase, we used the same two pairs of /tʰɒ/-/tʰʌ/ tokens from the test phase of the phonetic category learning task with the adult participants.

Apparatus and Procedure

Testing took place in a three-sided (210x190x210 cm) test booth within a sound attenuated dimly-lit laboratory room. The booth consisted of three off-white curtain walls, one situated in front on the infant and the other two at each of her side. Three 27” computer screens (ASUS VE276N, resolution 1920x180) were positioned in the middle of each curtain wall at the infant’s approximate eye level. They were used to display the visual stimuli (silent animated video or picture) for each part of the study. Three loudspeakers (M-Audio StudioPhile AV30 version 2), hidden by the curtain walls, were positioned behind each computer screen. A camera (Sony HDR-HC9E) located on top of the central screen allowed the experimenter situated outside of the testing room to control the infant’s looking behaviour on a computer screen. The experimenter, blind to the trial type presented to the infants, controlled the audio and visual stimuli presentation and coded online the infant’s looks by pressing keys on a keyboard of a second computer. Stimulus presentation and online coding looking times were controlled by the same custom-designed MATLAB software (R2017b, MathWorks, Inc.; WISP - *Wisconsin Infant Studies Program* developed by Rob Olson & Jenny Saffran, University of Wisconsin-Madison).

The Head-turn preference procedure was used for this experiment. Infants were first familiarized with the presentation of auditory stimuli not contingent on their looking behaviour (passive listening), followed by a test phase in which looking times towards contrastive materials were measured. Discrimination will be indicated by different looking times towards each type of test trials.

Before testing, each infant was randomly assigned to one of the two experimental conditions: the Minimal Pair or the Non-Minimal Pair condition. Infants were seated on their caregiver's lap at approximately 55 cm of the screens. During testing, the caregiver listened to music displayed through headphones and was instructed to remain quiet and to refrain from interfering with the infant's reaction to the stimuli.

During familiarization, a silent video of passing clouds was displayed on the central screen while the audio stimulus was played through the speaker situated behind the same central screen. During the last minute of the familiarization, the infants completed a training phase manually triggered by the experimenter. During this phase, the audio stimulus remained the same as the familiarization but the visual stimulus on the central screen was changed to a silent blinking light. Once the infant looked at the blinking light, it disappeared from the central screen and reappeared on one of the two side screens. The blinking light stayed on the side screen until the infant stopped looking at it or if she looked away for 2 seconds. In this case, it reappeared on the central screen to attract again the infant's attention. This training phase was used to visually familiarize the infants to the fact that pictures could appear on other screens than the central one. In total, the familiarization with the training phase lasted two minutes and a half.

During the test phase, the presentation of the audio stimuli was dependent of the infant's looking behaviour. At the beginning of each test trial, a silent animated picture of a spinning pinwheel appeared on the central screen to attract the infant's attention. Once the infant looked at the central screen, the pinwheel disappeared and reappeared on one of the two side screens. When the infant oriented her look toward the correct side screen, the audio stimulus was played through the loudspeaker located behind the corresponding screen. The audio stimulus stopped to play if the infant looked away for 2 seconds or if she reached the maximum trial length (21 s). In these cases, the pinwheel picture was displayed again on the central screen. A test trial was repeated if the infant's total looking time was less than 2 seconds.

During familiarization, the infants listened to a unique trial consisting in the 2 minutes and 30 second long familiarization string corresponding to their experimental condition. During this trial, they heard 128 experimental pseudo-words (/*lit*^{h}*ɒ/, /lit*^{h}*ʌ/,* /*nut*^{h}*ɒ/, /nut*^{h}*ʌ*/). All the infants heard the same */t*^{h}*ɒ/* and */t*^{h}*ʌ/* tokens but in different word context. The infants in the Minimal Pair condition heard each 16 /*lit*^{h}*ɒ/, /lit*^{h}*ʌ/,* /*nut*^{h}*ɒ/ and /nut*^{h}*ʌ*/ tokens repeated twice. The infants in the Non-Minimal Pair condition were divided into two sub-conditions. Half of the infants heard each 16 /*lit*^{h}*ɒ/* and 16 *nutuh* tokens repeated four times but never heard the */lit*^{h}*ʌ/* or /*nut*^{h}*ɒ/* tokens. Conversely, the other half of the infants heard each

16 */lit*ʰ*ʌ/* and 16 */nut*ʰ*ɒ/* tokens repeated four times but never heard the */lit*ʰ*ɒ/* or */nut*ʰ*ʌ/* tokens.

During the test phase, the infants were presented with eight test trials. The test trials consisted of isolated */t*ʰ*ɒ/-/t*ʰ*ʌ/* tokens separated by a 500 ms interstimulus interval. Two types of test trials were presented: the *Alternating trials* repeating the two test tokens (*/t*ʰ***ʌ****/-/t*ʰ***ɒ****/-/t*ʰ***ʌ****/-/t*ʰ***ɒ****/...*) and the *Non-Alternating trials* repeating only one type of the test tokens (*/t*ʰ***ɒ****/-/t*ʰ***ɒ****/-/t*ʰ***ɒ****/-/t*ʰ***ɒ****/...* and */t*ʰ***ʌ****/-/t*ʰ***ʌ****/-/t*ʰ***ʌ****/-/t*ʰ***ʌ****/...*). All the infants heard two blocks of four test trials, each block containing two *Alternating trials* and two *Non-Alternating trials*. The presentation of the trial was quasi random: the last test trial of the first test block and the first test trial of the second test block were never of the same type. In total, testing lasted around 5 minutes.

3.3.2 Results and Discussion

For each test block, the mean looking times towards the Alternating and Non-alternating trials were computed.

A pre-analysis of the data was performed by computing the general mean looking time across all trials to check for possible looking time outliers (± 2 standard deviations from the mean). This resulted in the exclusion of one participant from the Non-Minimal Pair condition.

We ran the same analysis as Feldman et al. (2013) that included Block (1 vs. 2) as variable. As the expected significant main effect of Block (9406 ms in block 1 vs. 6748 ms in block 2; $F=41.01$, $p<0.001$) did not interact with the other, it was no longer considered in the analysis and data from both blocks was analysed together. Results are shown in Figure 3.1.

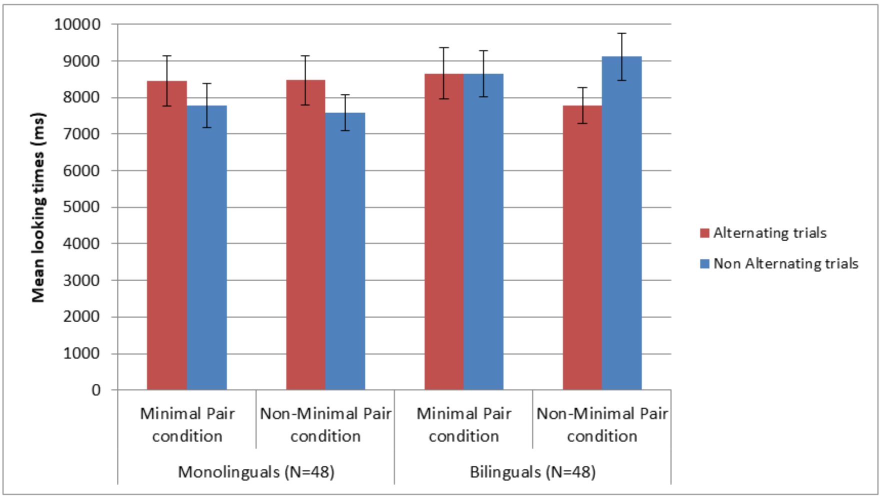

Figure 3.1. Mean looking times (ms.) and standard errors towards the Alternating (red) and Non-Alternating trials (blue) in each experimental condition for the monolinguals (left) and bilinguals (right).

For the Minimal Pair condition, the mean looking times were 8450 milliseconds (ms) for the Alternating trials and 7792 ms for the Non-Alternating trials. For the Non-Minimal Pair condition, the mean looking times were 8477 ms for the Alternating trials and 7590 ms for the Non-Alternating trials. These mean looking times values are in the same range as the values observed by Feldman et al. (2013a, personal communication) suggesting that across both studies, the infants were interested by the stimuli in similar ways.

A 2 x 2 Condition (Minimal Pair vs. Non-Minimal Pair) x Trial type (Alternating vs. Non-Alternating) mixed ANOVA was performed and showed a main effect of Trial type ($F(1, 46)=5.00$, $p=0.030$)

reflecting higher mean looking times to the Alternating trials than to the Non-Alternating trials (8463 ms vs. 7691 ms respectively). This is the opposite looking pattern to the one found by Feldman et al. (2013) whose participants generally showed a preference for the Non-Alternating trials. However, it is in agreement with previous research reporting longer looking times for alternating over non-alternating trials (Bertoncini, Nazzi, Cabrera & Lorenzi, 2011). We will come back to this point in the General Discussion.

Importantly, the main effect of Condition and the Condition by Trial type interaction did not reached significance (F<1). This suggests that our participants were not sensitive to the experimental conditions and displayed similar looking times towards the Non-Alternating and Alternating trials in both conditions.

Taken together, these results suggest that 8 month-old Spanish and Catalan monolingual infants discriminated the /ɒ-ʌ/ contrast regardless of the experimental condition. This does not replicate the pattern found by Feldman et al. (2013a) where English monolingual infants discriminated a native vocalic contrast in the Non-Minimal Pair condition but not in the Minimal Pair condition. Unlike their adult peers, 8 month-old monolingual infants do not seem to be sensitive to word-level information not related to meaning when learning a non-native contrast. We will discuss the results in the General Discussion section.

Experiment 2 investigates if Spanish-Catalan bilingual infants show the same pattern of results.

3.4 Experiment 2

The collection of data from this experiment was run in parallel with the previous one. The fact that monolinguals discriminated the /ɒ-ʌ/ non-native contrast, but were not sensitive to the experimental manipulation was unexpected. Given these results, we expected bilinguals also to discriminate the /ɒ-ʌ/ contrast. Also, considering the results of the monolingual infants and the reduced sensitivity to word-level information observed in the previous chapter for the simultaneous Spanish-Catalan adult participants, we expected bilinguals to replicate the infant monolingual pattern.

3.4.1 Methods

Participants

A total of forty-eight 8 month-old Spanish-Catalan bilingual infants were tested and included in the analysis (24 boys, age range= 235-273 days, mean=256 days). Nine additional infants were tested but not included in the final analysis due to: experimenter's error or technical issue (N=2), crying or fussiness (N=4), looking time outlier (N=1, see Results and Discussion section) and parental interference (N=2). An additional group of 12 infants has been tested but excluded from the analysis due to an experimental error.

All participants were healthy, full-term infants (> 37 GW) and had no known hearing deficits. The bilingual status of the infants' language background was assessed through the same linguistic questionnaire as in Experiment 1 (Bosch & Sebastián-Gallés, 2001).

All participants were exposed to both Catalan and Spanish on a daily basis, the exposition to their main language being up to 75% of the time. The research was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). Written informed consent was obtained from the participants' caregiver before the experiment was conducted.

Stimuli, Apparatus and Procedure

Same as in Experiment 1

3.4.2 Results and Discussion

As for the monolinguals, the mean looking time towards the Alternating and Non-alternating trials were computed for each test block. The pre-analysis of the data checking for possible looking time outliers resulted in the exclusion of one participant from the Non-Minimal Pair condition.

The analysis including the Block variable (1 vs. 2) showed the expected significant main effect (10109 ms in block 1 vs 6998 ms in block 2, $F=65.32$, $p<0.001$). As the variable did not interact with the other variables, it was removed from the analysis and data was analysed together. Results are shown in Figure 3.1.

For the Minimal Pair condition, the mean looking times were 8666 ms for the Alternating trials and 8642 ms for the Non-Alternating trials. For the Non-Minimal Pair condition, the mean looking times were 7785 ms for the Alternating trials and 9120 ms for the Non-Alternating trials. These values are in the range of the ones obtained with the monolinguals in Experiment 1 suggesting that bilinguals and monolinguals were interested by the stimuli in an equivalent way.

The 2 x 2 Condition (Minimal Pair vs. Non-Minimal Pair) x Trial type (Alternating vs. Non-Alternating) mixed ANOVA was performed but contrary to the monolinguals, there was no significant main effect of Trial type ($F(1, 46)=1.78$, $p=0.189$). This result suggests that overall, bilingual infants displayed similar looking times towards each type of trials. Both the main effect of Condition and the Condition by Trial type interaction did not reached significance ($F<1$). This suggests that bilinguals behaved similarly in both experimental conditions and displayed similar looking times towards Non-Alternating and Alternating trials in both conditions.

Taken together, these results indicate that Spanish-Catalan bilinguals do not seem to be sensitive to word-level information. Next, we analysed the results of monolingual and bilingual infants together to see if they showed different patterns of results.

Pooled analysis of Experiment 1 and 2

The results in Experiment 1 and 2 suggest that at 8 months old, both monolingual and bilingual infants may not be sensitive to word-level information.

However, visual inspection of the data showed an opposite pattern for the two populations concerning the discrimination of the /ɒ-ʌ/ contrast: monolinguals looked longer to Alternating trials ($p=.03$), while bilinguals seemed to look longer to Non-Alternating trials ($p=.189$). To test whether the two populations behaved differently, we analysed the data of the two studies together.

A 2x2x2 Language (Monolingual vs. Bilingual) x Condition (Minimal Pair vs Non-Minimal Pair) x Trial type (Alternating vs. Non-Alternating) mixed ANOVA was performed and showed a significant Language by Trial Type interaction ($F(1,92)= 5.652$, $p=.019$). This interaction suggests that the two groups of infants behaved differently.

Overall, the results with monolinguals and bilinguals indicate that they were not sensitive to the type of familiarisation. However, both populations differed in their ability to discriminate the contrast in the test phase.

3.5 General Discussion

The goal of the present research was to investigate if word-level information not related to meaning can influence how monolingual and bilingual 8 month-olds perceive a non-native vocalic contrast. In Experiment 1, we found that Spanish and Catalan monolinguals discriminated the non-native contrast regardless of the familiarization they have been exposed to. In Experiment 2, simultaneous Spanish-Catalan bilinguals, contrary to monolinguals, did not show discrimination of the non-native contrast in any experimental conditions.

These results suggest that both monolingual and bilingual infants were not sensitive to the type of familiarization and by extension, to word-level information. Overall, we are not replicating the pattern found by Feldman et al. (2013a) who showed that when learning a native contrast, English monolingual 8 month-olds were sensitive to word-level information as they discriminated the contrast in the Non-Minimal Pair condition but not in the Minimal Pair condition. According to Feldman et al. (2013a), the clearer word context in the Non-Minimal Pair condition helped their participants to separate the overlapping sounds. In our experiment, the absence of difference between the Minimal Pair and Non-Minimal Pair conditions, suggests that our participants were not able to use such information. We will discuss first the results of the monolingual infants.

One fundamental difference between our experiment and Feldman et al. (2013a)'s is that the contrast was non-native for our participants, while for Feldman et al. (2013a)'s participants it was a native one. Tuning to the native vowel system has been observed at 6 months of age (Kuhl, 1979; 1983; Kuhl et al., 1992). However, as Feldman et al. (2013a) indicated, the acquisition of the vowel space is incomplete at 8 months and the existing research shows mixed results. Some studies have shown lack of discrimination of non-native vowels at this age (Bosch & Sebastian-Galles, 2003), but other studies have shown no differences between native and non-native discrimination (Polka & Bohn, 1996). In general, it seems that the infants' abilities to discriminate foreign/non-native sounds are correlated with the adults' ones. Bosch and Sebastian-Galles (2003) had explored the capacity to perceive the Catalan-specific /e-ɛ/ vocalic contrast that is very difficult to perceive by native Spanish adults (Pallier, Bosch & Sebastian-Galles 1997; Bosch, Costa & Sebastian-Galles, 2000; Sebastian-Galles & Baus, 2005; Sebastian-Galles, Rodriguez-Fornells, de Diego-Balaguer & Diaz, 2006). Polka and Bohn (1996) compared the perception of the German /u-y/ and English /æ-ɛ/ vocalic contrasts in adult English and German natives and reported very high levels of performance for both native and non-native contrasts. The authors also tested English and German infants from 6 to 12 months of age and observed no differences between native and non-native performance for any age. From the only two available set of studies allowing for direct comparison between adult and infant discrimination, it seems that there is a parallel between adult and infant ability to discriminate foreign/non-native contrasts. In our investigation, the monolingual adult participants in the previous chapter showed a very good performance when discriminating the non-native /ɒ-ʌ/ contrast: in Experiment 3, without any pre-exposure, the monolinguals mean d' score was of 3.08. It is therefore reasonable to assume that in the present experiment, 8-month-old Spanish and Catalan monolinguals were quite good at discriminating this same non-native contrast before exposure, just as their adult peers. However, discrimination may not have been as good as for a native contrast. Indeed, in the Experiment 3 of the previous chapter, Spanish and Catalan monolinguals performed significantly worse than British English native participants (whose d' score was of 4).

Finally, regarding the absence of sensitivity to word-level information, it is possible that the 2-minute and a half familiarization to the Minimal Pair or to the Non-Minimal Pair condition may not have been long enough to induce any robust familiarization effect in our participants. This could explain why we observed discrimination (as shown by the main effect of trial type), but no effect of familiarization. We have planned to test this hypothesis by running two different studies: first, by testing infants without any previous familiarisation and second, by extending the familiarisation period. Because it would be very difficult to extend the familiarisation in the laboratory (the current 2 minutes and a half are already quite long), we will ask parents to play some audio files at home, before coming to the lab.

One important observation of the present investigation is the contrasting pattern of results between our monolingual and bilingual participants: monolingual infants showed discrimination of the non-native contrast while bilinguals did not. In the Experiment 3 of the previous chapter, simultaneous bilingual adults showed higher discrimination than monolinguals without any familiarization ($p=.041$), and the comparison of the overall performance of Experiments 1 and 2 almost yielded a significant difference ($p=.051$). Given the results of the adult participants, it was expected that bilingual infants would have no difficulties in perceiving the contrast. However, different studies investigating the capacity of 8-

month-old Spanish-Catalan bilinguals have shown lack of discriminatory abilities in this population for native vowel contrasts (Bosch & Sebastian-Galles, 2003; Sebastian-Galles & Bosch, 2009; but see Albareda-Castellot et al., 2011). Bosch and Sebastian-Galles (2003) as well as Sebastian-Galles and Bosch (2009) found that 8-month-old Spanish-Catalan bilinguals failed to show discrimination when familiarized to native vocalic contrasts, either existing in just one of the languages (the Catalan-specific /e-ε/ contrast) or in both (the common /o-u/ contrast). In the light of these two studies, it is likely that the lack of discrimination by our bilingual participants in Experiment 2 replicates those results. Because in Bosch and Sebastian-Galles (2003), discrimination was recovered at 12 months, one option would be to test participants at this age (although in this case, the results would not be directly comparable to Feldman et al's). Alternatively, we could test older infants with a completely different paradigm.

Sensitivity to word-level information has been found in 15 month-old infants (Thiessen, 2007; Thiessen & Yee, 2010). If the lack of discrimination in 8-month-old bilinguals masked the possible influence of word-level information, older infants should be able to discriminate the contrast as well as being sensitive to word-level information. This experiment could clarify if the present result is another demonstration of the previously reported lack of discrimination in Spanish-Catalan 8-month-olds[4], or if it is reflecting other processing differences between monolinguals and

[4] It is worth noticing that no convincing explanation for such lack of discrimination has been provided so far.

bilinguals. Regardless of the explanation, the present investigation reports for the first time a difference in monolingual and bilingual non-native phoneme discrimination in the first year of life.

Supplementary information

Additional analyses experiment 2

Minimal Pair condition

For this condition, the monolinguals had a mean looking time of 8450 milliseconds (ms) for the Alternating trials and of 7792 ms for the Non-Alternating trials. The bilinguals had a mean looking time of 8666 ms for the Alternating trials and 8642 ms for the Non-Alternating trials.

A 2 x 2 Language (Monolingual vs. Bilingual) x Trial type (Alternating vs. Non-Alternating) mixed ANOVA was performed. However, none of the tested variables nor the interaction reached significance ($F<1$ for all). This result suggests that in the Minimal Pair condition, monolinguals and bilinguals behaved similarly and showed similar looking times towards the Alternating and Non-alternating trials.

Non-Minimal Pair condition

For this condition, the monolinguals had a mean looking time of 8477 ms for the Alternating trials and of 7590 ms for the Non-Alternating trials. The bilinguals had a mean looking time of 7785 ms for the Alternating trials and 9120 ms for the Non-Alternating trials.

The 2 x 2 Language (Monolingual vs. Bilingual) x Trial type (Alternating vs. Non-Alternating) mixed ANOVA was performed and did not show any significant main effect ($F<1$ for both). Importantly, the analysis showed a significant Language by Trial type interaction ($F(1, 46)=6.85$, $p=0.012$). This interaction reflects larger increase in looking times between the monolinguals and bilinguals for the Non-Alternating trials when compared to the Alternating trials.

Test of simple effect showed a significant effect of Trial type for the bilinguals who showed significantly longer looking times for the Non-Alternating trials than for the Alternating trials ($t(23)=-2.11$; $p=0.046$). There was no significant effect of trial type for the monolinguals. These results suggest that in the Non-Minimal Pair condition bilinguals discriminated the /ɒ-ʌ/ contrast while monolinguals did not.

In the Minimal Pair condition, both monolinguals and Spanish-Catalan bilinguals displayed similar looking times towards each type of test trials suggesting that they did not discriminate the /ɒ-ʌ/ contrast. However, in the Non-Minimal Pair condition, only the bilinguals displayed significantly longer looking times toward the Non-Alternating trials suggesting that they discriminated the /ɒ-ʌ/ contrast.

4. EXPERIMENTAL SECTION 3

COMPARING MONOLINGUAL AND BILINGUAL LEXICON: THE CASE OF THE BACKWARD SEMANTIC INHIBITION

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4.1 Abstract

In the field of bilingual language acquisition, the establishment of the semantic system remains under investigated. Previous research with monolingual toddlers has shown that the appearance of semantic inhibitory effects (backward semantic inhibition) in 18- and 24-month-olds was modulated by the vocabulary size (Chow et al., 2019). In the present research, we investigated the emergence of semantic inhibitory effects in bilingual toddlers by assessing the backward semantic inhibition. We adapted the design by Chow et al. (2019) from English to Catalan and tested both Catalan monolingual and Spanish-Catalan bilingual 18- to 24-month-old toddlers. As in Chow et al. (2019) participants were split into small and large vocabulary size groups. Following the lack of replication in our results, a second group of monolingual and bilingual toddlers was tested with the same stimuli as Chow et al. (2019). The results partially replicated the results found by Chow et al. (2019) but their interpretation was limited by the small sample size. Together, our

results did not allow us to draw firm conclusions on the emergence of inhibitory effects in bilingual toddlers.

Keywords: semantic system, backward semantic inhibition, eye-tracking, bilingual toddlers

4.2 Introduction

In the field of bilingual language acquisition, one main area of research that still remains under investigated is the establishment of the semantic system. This system consists in the storage of word forms and their corresponding meanings. As the lexicon grows, toddlers are faced with the task of organizing such information to ultimately establish adult-like semantic networks with words and concepts linked together by facilitatory and inhibitory connections. Bilingual children have the supplementary task to organize their semantic system in both of their languages. However to date, little is known about how the information in the bilingual mental lexicon is organized.

One important property of the monolingual lexicon is that the processing of a word can be facilitated or inhibited by the previous appearance of another word. When a word is activated, it spreads its activation to other words semantically related to it (Collins & Quillian, 1969; see Neely, 2012 for a review). This spreading of activation results in the facilitation of the processing of subsequently presented new words semantically related to a previous one. For example, the recognition of the word “window” is faster if preceded by the word “door” than preceded by the word “elbow”. Interestingly, the recognition of “window” is inhibited (it is recognized slower) when preceded by “elbow” than when preceded by a neutral stimulus (for instance, by a tone, or a row of letter, if stimuli are printed). The existence of facilitatory effects has been widely reported in toddlers (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009). Recently, semantic inhibitory effects have been also found in children as young as 18-24 months of age (Chow, Aimola-Davies, Fuentes & Plunkett, 2016, 2019). The majority of the research investigating the emergence of the semantic system in bilinguals has focused on the emergence of facilitatory effects. The goal of the present research is to investigate the emergence of semantic inhibitory effects in bilingual toddlers.

A significant number of studies investigating semantic priming effects in monolingual toddlers have followed the experimental paradigm developed by Plunkett and co-workers. In these studies toddlers were auditory presented with a prime sentence followed by a target word that was either semantically related (e.g “I saw a cat (prime)! Dog (target)!”, related-prime trials) or unrelated (e.g, “I saw a tree! Cup!”, unrelated-prime trials) to the prime. They were then presented with a pair of two pictures, one of them depicting the target word. Significant differences in looking times towards the target picture between the related-prime and unrelated-prime trials are considered as evidence of semantic priming.

When investigating the monolingual lexicon in toddlers with this experimental paradigm, Plunkett and co-workers have found that the number of words modulated the semantic activation. Styles and

Plunkett (2009) as well as Arias-Trejo and Plunkett (2009, 2013) have reported semantic priming in both 21- and 24 month-olds but not at 18 month-olds. In their studies, only the older participants looked significantly more in the related-prime trials compared to the unrelated-prime trials. Moreover, the looking times to the target were significantly above chance only in the related-prime trials. These results suggest that target recognition was impaired by the presentation of an unrelated prime in a forward fashion. For the younger participants, only facilitatory effects were found as they displayed similar looking times towards the target regardless of the nature (related or unrelated) of the prime. To be noted, Arias-Trejo and Plunkett (2013) did not find semantic priming in 21 month-olds, however this divergent result may likely be due to the nature of the stimuli. In their study, the semantic relationship between the prime and target words was weaker than in the other two studies (only associatively or only taxonomically related vs. both associatively and taxonomically related). As mentioned before, the lexicon is composed by facilitatory and inhibitory connections. These results suggest that facilitatory links emerge earlier in the toddlers' lexicon and that inhibitory links appear with the increase of the vocabulary size.

Several investigations have used this paradigm to study semantic priming in bilingual toddlers. These studies compared the size of facilitatory effects in the two languages of the bilinguals and/or across the two languages. To our knowledge, the first study using this procedure was reported by Singh (2014) who investigated cross-language semantic priming in English-Mandarin 30 month-old bilinguals. Participants were tested both within (prime and target in the same language) and across their two languages (prime and target in different languages). The results showed semantic priming effect only when the prime was presented in the toddlers' dominant language. In this case, toddlers looked significantly more to the target in the related-prime trials compared to the unrelated-prime trials and this, regardless of the fact that the target was in the same language as the prime or not. These results suggest both within and across language priming effects but only in the toddlers' dominant language. Interestingly, the looking times to the target were significantly above chance only in the related-prime trials suggesting that the presentation of an unrelated prime interfered with the process of target recognition. Taken together, these results suggest that at 30 month-olds, bilinguals' semantic system contain both facilitatory and inhibitory connections and this, both within and across their two lexica.

In a similar study, Jardak and Byers-Heinlein (2019) tested 24- and 30 month-old English-French bilingual toddlers. A group of 24 month-olds was first tested on within language priming (i.e prime and target in the same language) in both of their languages. Results showed no evidence of semantic priming in both the bilinguals' languages as children increased their looking times to the target in both the related-prime and unrelated-prime trials. Thirty month-olds showed a different pattern when tested on both within and across language priming. For both within and across priming, toddlers showed semantic priming as they looked significantly more to the related- than to the unrelated-prime target. Again, the looking times were at chance for the unrelated-prime trials suggesting an interference of the unrelated prime on the process of target recognition. The results with the 30 month-olds did not completely replicate the pattern found by Singh (2014) as English-Mandarin bilinguals showed semantic priming only when the prime was presented in their dominant language. The authors suggested that the difference may be due to the different pairs of languages learned by the participants.

Taken together, the results of the semantic priming studies show a complex/inconsistent pattern of results, but they can be interpreted as supporting that at 30 but not 24 month-olds, bilingual toddlers have developed semantic links both within and across their languages and stronger effects for the dominant over the non-dominant language.

As mentioned above, in a couple of recent studies Chow, Aimola-Davies, Fuentes and Plunkett (2016, 2019) have reported inhibitory effects of an unrelated prime on target recognition in a “backward” fashion, or backward semantic inhibition. Effects of backward semantic inhibition have been first reported in adults when switching between semantic categories (Fuentes, Vivas & Humphreys, 1999, Experiment 2). In a modified lexical-decision task, adult participants were first presented with a prime word (e.g “dog”) followed by an intervening stimulus which was either a word from a different semantic category (e.g “sea”) or a neutral string of letters (e.g “XXX”). In the test phase, participants were asked to decide if the target was either a word or a non-word. Importantly, the target and prime words were either semantically related (e.g. dog (prime) and cat (target)) or not (e.g dog-finger). Results showed that when the intervening stimulus was a word, participants displayed longer reaction times to the related-prime target than to the unrelated-prime target. In contrast, when the intervening stimulus was a neutral string of letters, reaction times did not significantly differ between the related- and unrelated-prime targets. The authors concluded that the shift of attention between the different semantic categories of the prime and the intervening word resulted in the inhibition of the prime, inhibition that consequently spread to the semantically related target (but not to the semantically unrelated target). As a result, reaction times to the related-prime target were slower. The absence of effects when the intervening stimulus was a neutral string of letters suggests that backward semantic inhibition only occurs when switching within the semantic space.

Chow, Aimola-Davies, Fuentes and Plunkett (2016, 2019) investigated backward semantic inhibition in both 24- and 18 month-olds. In their studies, toddlers were successively presented on a screen with pictures of three types of stimuli: a prime, an intervening stimulus and a pair of target and distractor (see Figure 4.1).

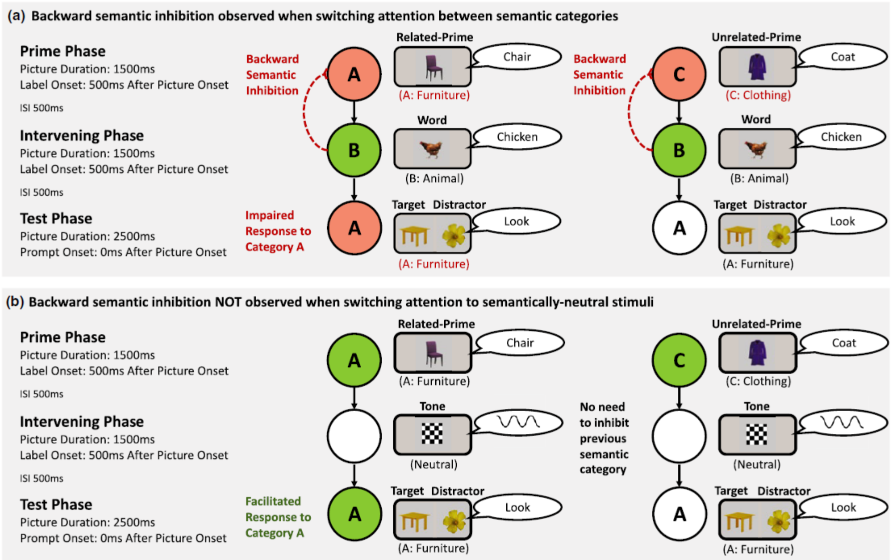

Figure 4.1. Detail of the backward semantic inhibition paradigm used in 24- and 18 month-olds by Chow et al. (2016, 2019). There are four types of trials: (a) Two intervening-word trials, including Related prime with Intervening word (left) and Unrelated prime with intervening word (right); (b) Two intervening tone trials, including Related prime with intervening tone (left) and Unrelated prime with intervening tone (right). Picture reproduced from Chow et al. (2019).

Toddlers heard the label of the prime and the intervening stimulus but there was no labelling of the target or distractor pictures to allow for a lexical decision by the toddlers. The prime and target pictures were either semantically related (e.g chair-table) or unrelated (e.g chair-hat). Importantly, the intervening stimulus was either a word (a picture and its corresponding label, intervening-word condition) or a tone (a checkerboard picture with a tone, intervening-tone condition). This manipulation was done to induce a shift of attention between semantic categories in the intervening-word condition but not in the intervening-tone condition. For the 24 month-olds, results showed that when the intervening stimulus was a word, toddlers looked significantly less at the related-prime target than at the unrelated-prime target while when the intervening stimulus was a tone, toddlers looked significantly more at the related- than at the unrelated-prime target. In other words, backward semantic inhibition was observed in the intervening word condition while facilitation was observed in the intervening tone condition. As in the adult study, in the intervening word condition, the switch of attention between semantic categories from the prime to the intervening word resulted in the inhibition of the prime. Subsequently, in the test phase participants' responses to the target picture were impaired for the related-prime target (because of its inhibitory connection to the prime) but not for the unrelated-prime target. In the intervening tone condition, there was no shift of attention within the semantic space preventing the occurrence of backward semantic inhibition. Subsequently, in the test phase participants' responses to the target picture were facilitated for the related-prime target but not for the unrelated-prime target.

Importantly for the present research, when testing 18 month-olds, Chow et al. (2019) found divergent results depending on the vocabulary size of the participants. While both toddlers with large and small vocabulary size showed facilitation in the intervening tone condition, only toddlers with large vocabulary size showed an effect of backward semantic inhibition in the intervening-word condition. This last result suggests that an increased word number in the lexicon (in other words, vocabulary size) modulates the appearance of inhibitory connections in the toddlers' lexicon.

The fact that the semantic facilitatory and inhibitory effects we have just described are modulated by the vocabulary size of the participants represents a window of opportunity to investigate the type of information responsible for such effects. Contrary to monolinguals, for bilinguals word forms and concept do not occur in the lexicon in a one-to-one correspondence as they ultimately learn two word forms (one in each language) corresponding to a unique concept. However, during development, bilinguals know some words in one language, some in the other language and some in both languages. Different studies have shown that compared to monolinguals, bilingual toddlers know less words in each of their languages (Hoff et al., 2012; Hoff, Rumiche, Burridge, Ribot, & Welsh, 2014). However, they have an equivalent number of concepts for which they know at least one word, the so-called, “conceptual vocabulary”. Thus, bilinguals’ word knowledge can be assessed differently: based on the word forms they know in the language of test and based on the “conceptual vocabulary”.

In the present investigation, we replicated the design by Chow et al. (2019) by adapting the original English stimuli to Catalan. As Chow et al. (2019) showed that it was the vocabulary size rather than the age that modulates the appearance of backward semantic inhibition, we tested a group of participants from 18 to 24 month-olds. To investigate the modulation of vocabulary size on the appearance of backward semantic inhibition, participants were split into large and small vocabulary size groups. Large and small vocabulary groups were determined in two ways: first based on the number of concepts for which bilinguals knew at least one word (conceptual vocabulary) and number of words known in the target language (Catalan vocabulary). As a control, a group of Catalan monolingual toddlers were also tested.

A series of two groups of experiments has been implemented. In the first group of experiments a group of Catalan monolinguals has been first tested (Experiment 1a) to validate the stimuli used with the Spanish-Catalan bilingual toddlers (Experiment 1b). Following the lack of replication in the results of the first experiment, a second group of experiment tested again both Catalan monolinguals (Experiment 2a) and Spanish-Catalan bilinguals (Experiment 2b) with the same stimuli as Chow et al. (2019).

4.3 Experiment 1a

In this experiment, we wanted to validate the stimuli to be used in the experiments with bilinguals. To this end, we replicated the experimental procedure and analysis Chow et al. (2019) extending it to a new sample, stimuli and language.

4.3.1 Methods

Participants

Sixty-six toddlers from 18 to 26 month-olds were tested (mean age=20 months 14 days; age range=18 months 1 day – 25 months 24 days; 34 boys) and included in the analysis. Twenty-six additional toddlers were tested but excluded from the analysis for the following reasons: crying or fussiness (N=8), bad quality of eye-tracking data (N=5), not enough trials available (See Results and Discussion below, N=8) and parental interference (N=5).

Participants were recruited by visiting maternity rooms at private hospitals (the Hospital Quirón and the Clínica Sagrada Familia) in Barcelona, Spain. All participants were healthy, full-term infants (> 37 GW) and had no known hearing deficits. A linguistic questionnaire (adapted from Bosch & Sebastian-Galles, 2001) was administered to determine infants' language background and familiarity. Participants were exposed to Catalan at least 90% of the time.

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). All parents signed informed consent for their infants to participate in this study.

Stimuli

The stimuli were adapted from the study by Chow et al. (2019). Toddlers were presented with four types of stimuli: a prime-phase stimulus, an intervening-phase stimulus, and two test-phase stimuli: a target and a distractor. The prime-phase stimuli were the picture and audio label of either a t-shirt (50% of trials) or a spoon (50% of trials). The intervening-phase stimuli were the picture and audio label of either a bath soap (25%) or baby keys (25%) for half of the trials and a picture of a diamond (25%) or square (25%) checkerboard accompanied by a tone for the other half of the trials. In the test phase, the target stimuli were the pictures of either a pair of socks (50%) or a fork (50%) while the distractors pictures were either a table (50%) or a baby brush (50%, see Annex 1).

As in Chow et al. (2016, 2019), the prime and target stimuli were semantically related: “t-shirt-socks” and “spoon-fork” are both taxonomically related and associated. The intervening words were semantically unrelated to both the prime and target. Importantly, all the test words were non-cognates between Catalan and Spanish.

As in Chow et al. (2019), the stimuli were used to create four experimental conditions (see Figure 4.2). The two intervening word conditions were: Related Prime with Intervening Word (e.g, *samarreta-sabó-mitjons* (t-shirt-soap-socks), 4 trials) and Unrelated Prime with Intervening Word (e.g, *cullera-sabó-mitjons* (spoon-soap-socks), 4 trials). The two Intervening Tone conditions were Related Prime with Intervening Tone (e.g, *samarreta-tone-mitjons* (t-shirt-tone-socks), 4 trials) and Unrelated Prime with Intervening Tone (e.g, *cullera-tone-mitjons* (spoon-tone-socks), 4 trials).

Visual stimuli

As in Chow et al. (2016, 2019), realistic photographic representations were used. After selection, the objects were edited out of their original background and placed in the center of a 19.59 x 19.59 cm gray background using Adobe Photoshop.

For the prime and intervening stimulus phases, the pictures were centered in the middle of the screen. For the test phase, the two pictures were located in the middle left and middle right side of the screen, separated from each other by a visual angle of 19.8º. Stimulus saliency was also controlled during the test phase by

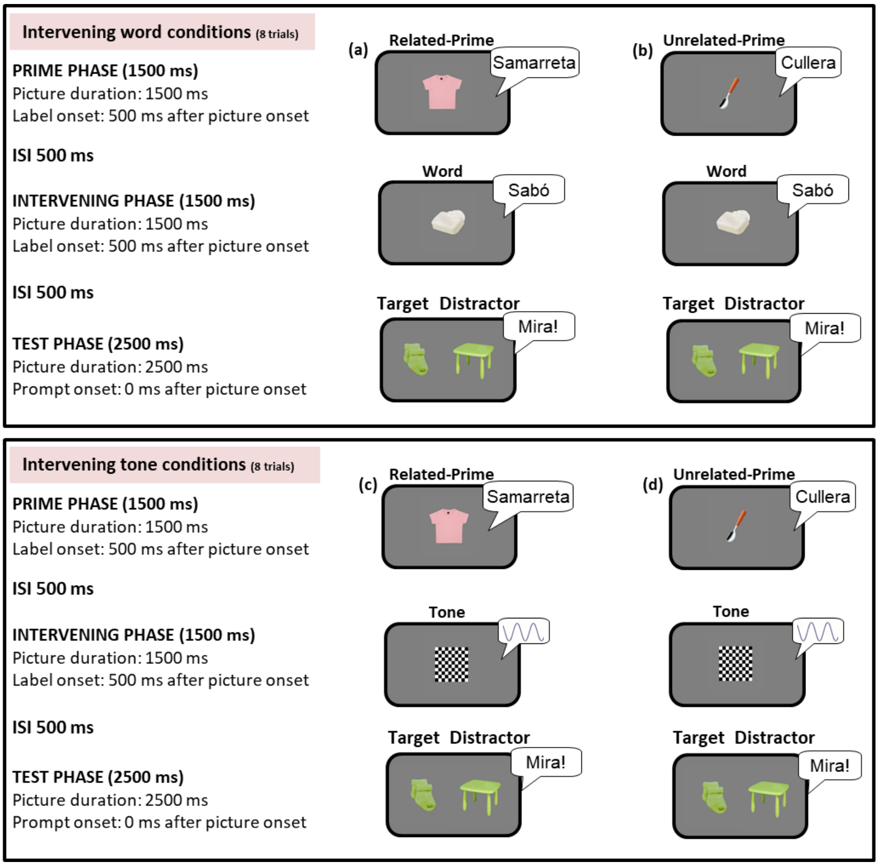

Figure 4.2 Details of the paradigm used in the present experiment (same as in Chow et al. (2019)). There were in total four experimental conditions: two intervening-word conditions (upper panel) including Related Prime with intervening word ((a), 4 trials) and Unrelated Prime with intervening word ((b), 4 trials); and two intervening-tone conditions (lower panel) including Related Prime with intervening tone ((c), 4 trials) and Unrelated Prime with intervening tone ((d), 4 trials).

ISI= Interstimulus Interval; *samarreta*: t-shirt; *cullera*: spoon; *sabó*: soap and *mira*: look.

matching the color (red, blue, yellow and green) of the target and distractor pictures in each trial.

To reduce boredom during testing, four different pictures were used for each prime, intervening stimulus, target and distractor tokens. To avoid color cuing within a trial, the prime, intervening, and test pictures were never in the same color. Within each trial, the prime and intervening pictures, if not presented in frontal views, faced in opposite direction. The prime and intervening pictures faced both the left and right side for an equal number of trials. In the test phase, the target and distractor pictures appeared on the left and right sides of the screen for an equal number of trials.

Four experimental orders were created to counterbalance for picture location and target and distractor combinations.

Auditory stimuli

The auditory stimuli were recorded in a sound attenuated booth by a native female Catalan speaker in a child-directed manner. The duration of the prime words was 989 milliseconds (ms) for the word "*samarreta*" (t-shirt) and 875 ms for the word "*cullera*" (spoon). The duration of the intervening word stimuli was 916 ms for "*claus*" (keys) and 804 ms for "*sabó*" (soap). The tone accompanying the square checkerboard was a 700ms-wave-tone in C and the tone accompanying the diamond checkerboard was a 700ms-wave-tone in D. They were the same audio stimuli used by Chow et al. (2016, 2019).

Two attention getting words were recorded for the test phase: the duration was 767 ms for “*mira!*” (look) and 989 ms for “*Ooh*” (wow).

Apparatus and Procedure

Testing took place in a sound-attenuated dimly-lit laboratory room. Toddlers sat on their caregiver’s lap at approximately 65 cm of a Tobii TX300 Eye-tracker and a 23-in. screen (1920x1080 pixels resolution). The sampling rate of the Eye-tracker was 120 Hz. Auditory stimuli were presented through two central loudspeakers (M-Audio Audiophile AV30) located behind the eye-tracker. A camera (Sony HDR-HC9E) located on top of the Eye-tracker allowed the experimenter situated outside of the testing room to monitor the infant’s eye movements.

Before testing, toddlers were randomly assigned to one of the four experimental orders. A five-point calibration was first performed with a colorful beach ball as calibration attention getter. If the first calibration was less than 4 points over 5, recalibration was performed to achieve good calibration. After calibration, toddlers were shown 16 trials presented in a random order generated by the Matlab testing software. Each trial was manually initiated by the experimenter by pressing the space bar when the toddler was looking at the screen. Eye movements were recorded using custom-made software (Matlab 2014a (8.3.0.532) at 64 bits with Psychtoolbox version 3.0.12).

Each trial began with the presentation of a 1000-ms attention getter, the same as the ones used by Chow et al. (2016, 2019). In the 1500-

ms prime phase, toddlers were shown a prime picture with its audio label. This prime was semantically related or unrelated to the target picture presented in the test-phase. The prime phase was followed by an intervening stimulus phase in which toddlers either saw a picture with its audio label (word condition) or a checkerboard accompanied by a sine wave tone (tone condition). Finally, there was a 2500-ms test phase during which a target and a distractor pictures were displayed along with an attention-getting word ("mira!" (look) or "Ooh!" (wow)). Like in the original study, the pictures were not named in the test phase to avoid any explicit directing of the toddler's attention to either picture. There was a 500-ms interstimulus interval (a blank screen in silence) between the prime and intervening phase and between the intervening and test phases. The stimulus onset asynchrony between the prime and target pictures was 4000 ms. In total, testing lasted around 3 minutes.

During testing, caregivers were instructed to keep their eyes shut, remain quiet, and refrain from any interactions with their infant during the experiment. After testing, caregivers were asked to fill a short version of the CDI adapted from Fenson et al. (2000). The vocabulary questionnaire was presented in Catalan but also in Spanish. Caregivers were invited to fill them both even if their child was only marginally exposed to Spanish.

Eye-tracking data processing

As for Chow et al. (2019), only the data from the test phase has been analysed. Eye-gaze data were converted into fixation data using the R package Gazepath (package gazepath version 1.2; van Renswoude & Visser, 2017).

For each participant and each experimental condition, fixation data between 0 and 2500 ms after picture onset was aggregated into fifty 50-ms time bins. In each time bin, toddler's target preference was measured (Target Preference = Looking Time to the Target / (Looking time to the Target + Looking time to the Distracter)).

An experimental design error was present in the present study: one of the prompts used in the test phase ("***mi**ra!*", look) shared a phonological overlap with the onset of one of the target picture ("***mi**tjons*", socks). As this phonological overlap may bias the toddler's looking response by always inducing a facilitatory phonological effect, trials where the prompt was "*mira!*" and the target picture was "*mitjons*" were removed from the analysis. After data pre-processing and the removing of the "mira-mitjons" trials, 8 participants were excluded from the analysis due to a low number of trials available (<7 trials). For the remaining participants, on average, 11 out of 16 trials from each participant were available for the analysis.

4.3.2 Results and Discussion

As in Chow et al. (2019), toddlers were split into large and small vocabulary size groups based on their receptive score in Catalan with the language questionnaire (median=62). The large vocabulary size group (N=33) understood a mean of 80 words (out of 99, range=62-99), while the small vocabulary size group understood a mean of 48 words (range=19-62). A Welch unequal variance t-test showed that the small vocabulary size group had a significantly lower CDI receptive score than the large vocabulary size group ($t(63.2)= 10.53$, $p<0.001$). For the test words used in the experiment, the large vocabulary group was reported to understand on average 7.3 of 8 words (range=5-8) and the small vocabulary size group 4.5 of 8 words (range=0-8). These numbers are in the same range as for Chow et al. (2019) whose toddlers in the large vocabulary size group understood on average 7.5 words and toddlers in the small vocabulary size group understood on average 5.1 words.

The overall pattern of the fixation data is shown in Figure 4.3. As in Chow et al. (2019), the time course of the fixation data was divided into two equal windows of analysis: the Window 1 from 300 ms to 1400 ms after picture onset and the Window 2 from 1401 ms to 2500 ms after picture onset. For each window of analysis, fixation data was entered into a binomial logistic mixed-effects model (R version 3.5.0, package lme4 version 1.1-21: function glmer). The same model as in Chow et al. (2019) was created with three fixed effects: Intervening stimulus (Word. Vs. Tone), Prime type (Related vs. Unrelated) and Vocabulary Size (Large vs. Small), and random effect of toddlers on the intercept.

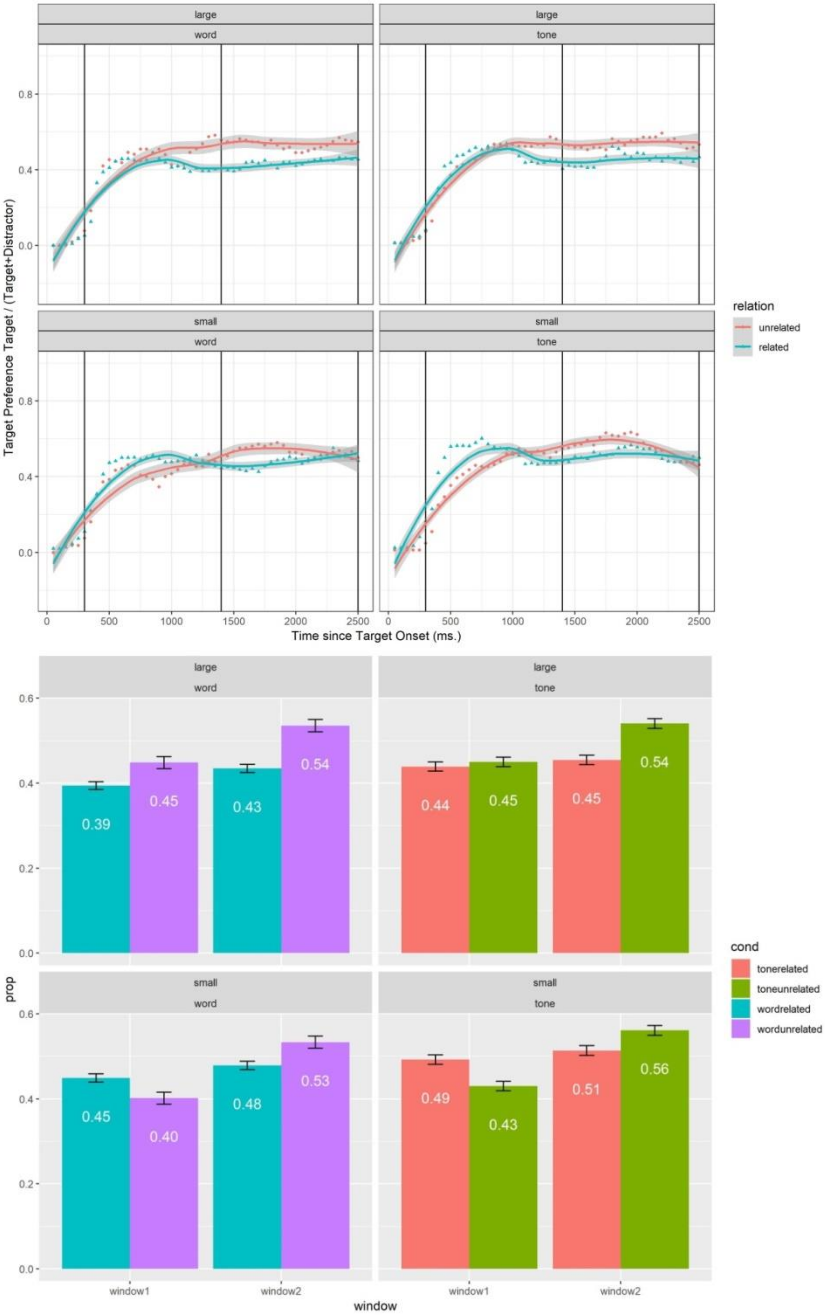

Figure 4.3 Monolingual toddlers' fixation data of Experiment 1a presented in time course (upper panel) and in aggregation (bottom panel) for each window of analysis (Window 1 (300-1400 ms) and Window 2 (1401-2500 ms)) for each vocabulary size group (large: up and small: bottom) in each intervening condition (intervening word: right and intervening tone: left). Error bars are standard errors.

Table 4.1 summarizes the results of the model for the Window 1.

Table 4.1. Results of Window 1 for the Monolingual participants (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone), Prime Type (Related vs. Unrelated) and Vocabulary size (Large vs. Small). *p<0.05

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	-0.34	0.08	-4.11	<0.001*
Intervening stimulus: Word (baseline: Tone)	-0.08	0.08	-1.01	0.313
Prime type: Related (baseline: Unrelated)	0.27	0.07	3.88	<0.001*
Vocabulary size: Large (baseline: Small)	0.09	0.12	0.80	0.425
Intervening stimulus: Word x Prime type: Related	-0.07	0.10	-0.72	0.473
Intervening stimulus: Word x Vocabulary size: Large	0.09	0.11	0.77	0.440
Prime type: Related x Vocabulary size: Large	-0.29	0.10	-3.06	0.002*
Intervening stimulus: Word x Prime type: Related x Vocabulary size: Large	-0.14	0.14	-0.95	0.342

In the Window 1, there was no significant main effect of intervening stimulus (Estimate=-0.08, p=0.313) or of vocabulary size (Estimate=0.09, p=0.425). There was also no significant interaction of intervening stimulus x vocabulary size (Estimate=0.09, p=0.440). There was a significant main effect of prime type (Estimate=0.27, p<0.001) indicating that across both intervening stimulus conditions and vocabulary size group, toddlers fixated more on the related-prime target than on the unrelated-prime target. However, the interaction of intervening stimulus x prime type was not significant (Estimate=-0.07, p=0.473). There was a significant interaction of prime type x vocabulary size (Estimate=-0.29, p=0.002). This last interaction reflected that toddlers from each vocabulary size group showed different direction of target preferences: toddlers from the large vocabulary size group fixated equally on both types of prime types (related: 0.45 vs. unrelated: 0.415, $t(32)<1$) while toddlers from the small vocabulary size group showed a tendency to fixate more on the related-prime target (related: 0.47 vs. unrelated: 0.415, $t(32)=1.56$, $p=0.12$). There was no significant 3-way interaction of intervening stimulus x prime type x vocabulary size (Estimate=-0.14, $p=0.342$).

In summary, in the Window 1, there was no effect of intervening stimulus and toddlers behaved similarly in the intervening-tone and intervening-word conditions. The absence of significant preference for the related-prime or the unrelated-prime target for each vocabulary size group, does not allow us to conclude about any facilitatory or inhibitory effects.

Table 4.2 summarizes the results of the model for the Window 2.

Table 4.2. Results of Window 2 for the Monolingual participants (1401-2500 ms) Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone), Prime Type (Related vs. Unrelated) and Vocabulary size (Large vs. Small). *p<0.05

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	0.26	0.08	3.17	0.002*
Intervening stimulus: Word (baseline: Tone)	-0.09	0.08	-1.25	0.213
Prime type: Related (baseline: Unrelated)	-0.19	0.07	-2.85	0.004*
Vocabulary size: Large (baseline: Small)	-0.09	0.12	-0.78	0.435
Intervening stimulus: Word x Prime type: Related	-0.05	0.10	-0.50	0.618
Intervening stimulus: Word x Vocabulary size: Large	0.08	0.11	0.77	0.441
Prime type: Related x Vocabulary size: Large	-0.16	0.09	-1.76	0.079
Intervening stimulus: Word x Prime type: Related x Vocabulary size: Large	-0.02	0.14	-0.16	0.877

In the Window 2, there was no significant main effect of intervening stimulus (Estimate=-0.09, p=0.213) or of vocabulary size (Estimate=-0.09, p=0.435). There was no significant interaction of intervening stimulus x vocabulary size either (Estimate=0.08, p=0.441). There was a significant main effect of prime type (Estimate=-0.19, p=0.004) indicating that across both intervening stimulus conditions and vocabulary size group, toddlers fixated less on the related-prime target than on the unrelated-prime target. However, the interaction of intervening stimulus x prime type was not significant (Estimate=-0.05, p=0.618) and the interaction of prime type x vocabulary size was marginal (Estimate=-0.16, p=0.079). The 3-way interaction of intervening stimulus x prime type x vocabulary size was not significant either (Estimate=-0.02, p=0.877).

In summary, in the Window 2, in both intervening stimulus conditions toddlers from both vocabulary size groups only showed a general preference to fixate on the unrelated-prime target.

Summarizing for the two windows of analysis in Experiment 1a, there was no effect of intervening stimulus or vocabulary size. In the Window 1, toddlers from both vocabulary size groups did not show any significant effects. In the Window 2, they showed a generalized preference for the unrelated-prime target.

These results do not replicate the effects of Chow et al. (2019). We present next the results of the bilinguals that were collected in parallel. We will discuss the results of both populations in the discussion section of Experiment 1a and 1b.

4.4 Experiment 1b

4.4.1 Methods

Participants

Thirty-nine toddlers from 18 to 26 month-olds were tested (mean age=21 months 14 days; age range=18 months 4 days – 25 months 29 days; 18 boys) and included in the analysis. Fourteen additional toddlers were tested but excluded from the analysis for the following reasons: crying or fussiness (N=3), technical problem (N=1), bad quality of eye-tracking data (N=3), not enough trials available (See Results and Discussion below, N=4) and parental interference (N=3).

The bilingual status of the infants' language background was assessed through the same linguistic questionnaire as in Experiment 1a (Bosch & Sebastián-Gallés, 2001). All participants were exposed to both Catalan and Spanish on a daily basis from birth, the exposition to their dominant language (Catalan) being up to 75% of the time.

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). All parents signed informed consent for their infants to participate in this study.

Stimuli, Apparatus and Procedure

Same as in Experiment 1a.

Eye-tracking data processing

Same as in Experiment 1a.

After data pre-processing and the removing of the “mira-mitjons” trials, 4 participants were excluded from the analysis. For the remaining participants, on average, 11 out of 16 trials from each participant were available for the analysis.

4.4.2 Results and Discussion

Toddlers were split into large and small vocabulary size groups based on their receptive concept score in the language questionnaire (median=80). As bilinguals may know fewer words than monolinguals in the same language (Hoff et al., 2012), the concept score was used for bilinguals to better assess their vocabulary size. The large vocabulary size group (N=19) understood a mean of 88 words (range=80-99), while the small vocabulary size group (N=20) understood a mean of 56 words (range=20-80). A Welch unequal variance t-test showed that the small vocabulary size group had a significantly lower CDI receptive score than the large vocabulary size group ($t(26.21)= 8.95$, $p<0.001$). For the test words used in the experiment, the large vocabulary group was reported to understand on average 7.7 words (range=6-8) and the small vocabulary size group 5.8 words (range=1-8). These numbers are similar to the ones of the monolinguals for the large vocabulary size group but a slightly higher for the small vocabulary size group (5.8 vs. 4.5).

The overall pattern of the fixation data is shown in Figure 4.4. Data fixation from each window of analysis was entered in the same binomial logistic mixed-effects model as in Experiment 1a.

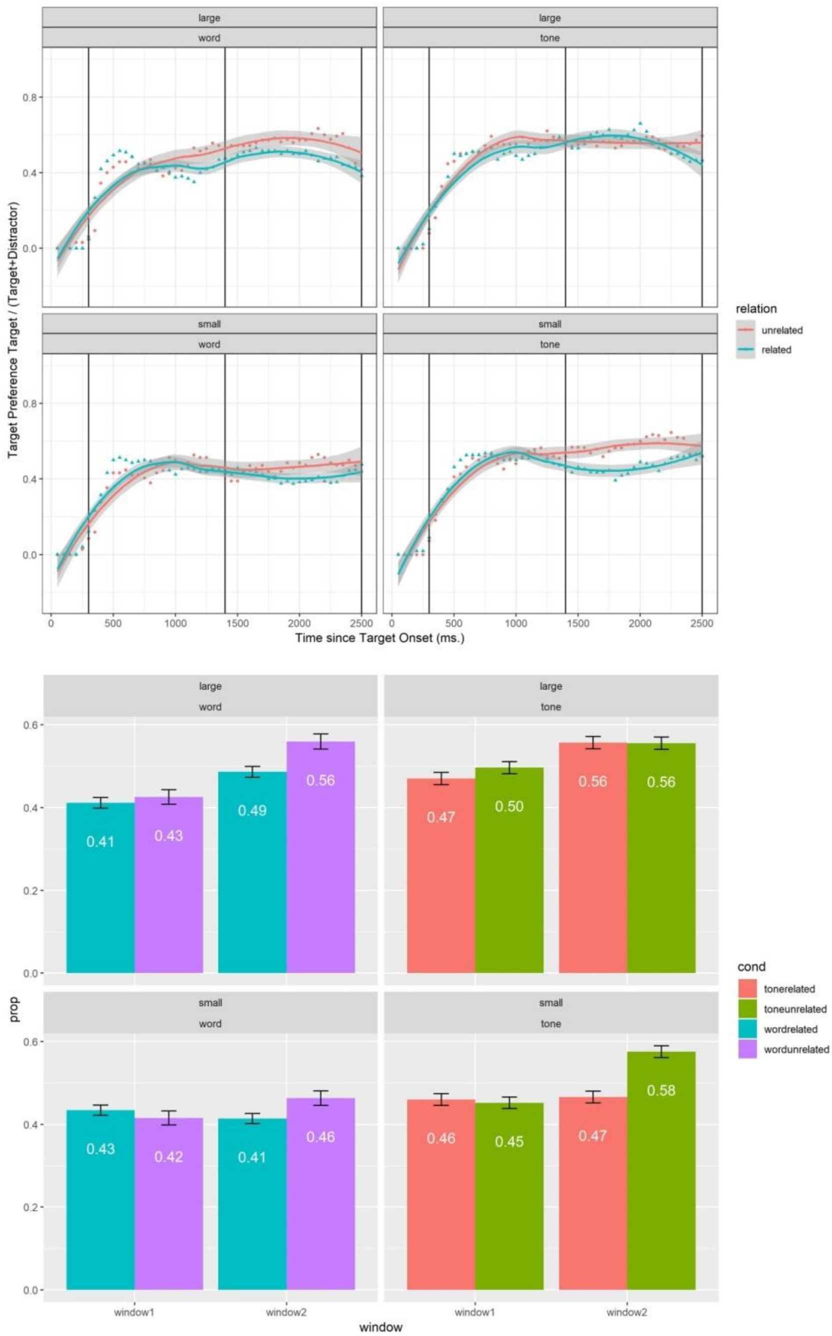

Figure 4.4 Bilingual toddlers' fixation data of Experiment 1b presented in time course (upper panel) and in aggregation (bottom panel) for each window of analysis (Window 1 (300-1400 ms) and Window 2 (1401-2500 ms)) for each vocabulary size group (large: up and small: bottom) in each intervening condition (intervening word: right and intervening tone: left). Error bars are standard errors.

Table 4.3 summarizes the results of the model for the Window 1.

Table 4.3. Results of Window 1 for the Bilingual participants (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone), Prime Type (Related vs. Unrelated) and Vocabulary size (Large vs. Small). *p<0.05

Fixed Effects	Estimates	SE	z	p
Intercept	-0.24	0.11	-2.08	0.038*
Intervening stimulus: Word (baseline: Tone)	-0.18	0.10	-1.89	0.059
Prime type: Related (baseline: Unrelated)	0.04	0.09	0.51	0.61
Vocabulary size: Large (baseline: Small)	0.19	0.16	1.18	0.24
Intervening stimulus: Word x Prime type: Related	0.07	0.12	0.56	0.58
Intervening stimulus: Word x Vocabulary size: Large	-0.12	0.14	-0.90	0.37
Prime type: Related x Vocabulary size: Large	-0.13	0.12	-1.03	0.31
Intervening stimulus: Word x Prime type: Related x Vocabulary size: Large	-0.03	0.18	-0.16	0.87

In the Window 1, there was a marginal main effect of intervening stimulus (Estimate=-0.18, p=0.059) indicating that across both prime types and vocabulary sizes, toddlers showed a marginal reduction in target preference in the intervening word condition compared to the intervening tone condition. There was no significant main effect of prime type (Estimate=0.04, p=0.61) or vocabulary size (Estimate=0.19, p=0.24). Importantly, none of the interactions tested were significant.

In summary, in the Window 1, no significant facilitatory or inhibitory effects were observed for any vocabulary size group in any intervening condition.

Table 4.4 summarizes the results of the model for the Window 2.

Table 4.4. Results of Window 2 for the Bilingual participants (1401-2500 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone), Prime Type (Related vs. Unrelated) and Vocabulary size (Large vs. Small). *p<0.05

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	0.31	0.10	3.18	0.001
Intervening stimulus: Word (baseline: Tone)	-0.47	0.09	-5.01	<0.001*
Prime type: Related (baseline: Unrelated)	-0.46	0.08	-5.52	<0.001*
Vocabulary size: Large (baseline: Small)	-0.09	0.14	-0.62	0.538
Intervening stimulus: Word x Prime type: Related	0.25	0.12	2.08	0.038*
Intervening stimulus: Word x Vocabulary size: Large	0.45	0.13	3.34	<0.001*
Prime type: Related x Vocabulary size: Large	0.46	0.12	3.82	<0.001*
Intervening stimulus: Word x Prime type: Related x Vocabulary size: Large	-0.53	0.18	-3.03	0.002*

In the Window 2, there was no main effect of vocabulary size (Estimate=-0.09, p=0.538) but there was a significant main effect of intervening stimulus (Estimate=-0.47, p<0.001) indicating that across both prime types and vocabulary sizes, toddlers showed a significant reduction in target preference in the intervening word condition compared to the intervening tone condition. The main effect of prime type was also significant (Estimate=-0.46, p<0.001) indicating that across intervening stimulus and vocabulary sizes, toddlers fixated less on the related-prime target than on the unrelated-prime target. Importantly, there was a significant interaction of intervening stimulus and prime type (Estimate=0.25, p=0.038) and two significant interactions of intervening stimulus and vocabulary size (Estimate=0.45, p<0.001) and of prime type and vocabulary size (Estimate=0.46, p<0.001). These three interactions were modulated by the significant triple interaction of intervening stimulus type x prime type x vocabulary size (Estimate=-0.53, p=0.002). For each vocabulary size groups, post-hoc models contrast with Bonferroni-corrected p-values were used. For the large vocabulary size group, when the intervening stimulus was a word, toddlers fixated significantly less on the related-prime target than on the unrelated-prime target (Estimate=-0.28; z=-3.03; p=0.005); when the intervening stimulus was a tone, toddlers fixated similarly on the related-prime and unrelated-prime target (Estimate<0.001; z<0.001; p=1). For the small vocabulary size group, when the intervening stimulus was a word, toddlers fixated significantly less on the related-prime target than on the unrelated-prime target (Estimate=-0.21; z=-2.36; p=0.037). When the intervening stimulus was a tone, toddlers also fixated significantly less on the related-prime target than on the unrelated-prime target (Estimate=-0.46; z=-5.52; p<0.001).

In summary, in the Window 2, bilingual toddlers with large vocabulary size showed backward semantic inhibition in the intervening-word condition. Bilingual toddlers with small vocabulary size did not show backward semantic inhibition but rather a general preference for the unrelated-prime target in both intervening stimulus conditions.

Summarizing for the two windows of analysis in Experiment 1b, there was an effect of intervening stimulus for the large vocabulary size group. In the Window 1, no significant facilitatory or inhibitory effects were observed for any vocabulary size groups. In the Window 2, bilingual toddlers with large vocabulary size showed backward semantic inhibition while bilingual toddlers with small vocabulary size only showed a preference for the unrelated-prime target.

Discussion

Taken together, the results of Experiment 1a and 1b show a complex pattern of results and importantly, they do not replicate the pattern found by Chow et al. (2019). For the monolinguals, no effect of intervening stimulus was found and both vocabulary size groups only showed a general preference for the unrelated-prime target. For the bilinguals, an effect of intervening stimulus was found for the large vocabulary size group who showed backward semantic inhibition while the small vocabulary size group only showed a general preference for the unrelated-prime target.

There are two possible methodological explanations why we failed to replicate Chow et al's results. The first one is that we had the semantic relatedness between our prime and target stimuli may not have been as strong as in the original stimuli in Chow et al. (2019). Selecting stimuli for the present type of experiments is always difficult. Stimuli must be words that are both easily picturable and known to infants. Toddlers have a quite restricted vocabulary and it cannot be used either arrows or partial pictures (like, for instance, it is done with adult research to depict a knee).

Our research question was to investigate what predicted better bilinguals' results: number of words in the target language or number of concepts for which they know a word. Because of bilinguals' parallel activation of their two lexicons (Costa, Sebastian-Galles, & Caramazza 2000, Von Holzen & Mani, 2012) we were forced to use only non-cognates. The percentage of cognates between Spanish and Catalan is around 60% of the words (estimated from the Spanish and Catalan versions of the CDI). This reduced substantially the potential candidate words. On top of these restrictions, the design used by Chow et al. (2016, 2019) requested that the intervening word and the prime shared their onset. Compliance with these restrictions might have resulted in a set of stimulus less optimal in terms of their familiarity and/or semantic relationship, when compared with Chow's et al. (2016, 2019). Preliminary (partial) analysis of the results of Experiment 1a pointed in the direction that we were far from replicating the original results.

Inspection of the images used by Chow et al. (2016, 2019) showed that they were culturally neutral and could be used in Barcelona too with very minor adjustments. Because the experimental procedures were quite short, it was decided to run our participants with both our stimuli and Chow's.

Experiment 2a and 2b explored if we could replicate the results found by Chow et al. (2019) with their own visual stimuli.

4.5 Experiment 2a

4.5.1 Methods

Participants

Twenty-five toddlers from 18 to 26 month-olds were tested (mean age=22 months 14 days; age range=18 months 5 days – 25 months 24 days; 13 boys) and included in the analysis. Nineteen additional toddlers were tested but excluded from the analysis for the following reasons: improper calibration (N=1), crying or fussiness (N=11), bad quality of eye-tracking data (N=4), not enough trials available (N=2) and parental interference (N=1). Following an error in the experimental design (see Eye-tracking data pre-processing part below), 11 additional toddlers included at first had to be removed from the analysis.

The same linguistic questionnaire as in Experiment 1a and 1b was administered to determine the toddlers' language background and familiarity. Participants were exposed to Catalan at least 90% of the time.

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). All parents signed informed consent for their infants to participate in this study.

Stimuli

The stimuli were the same as the one used by Chow et al. (2019) except for the coat picture that was replaced by a jacket. Indeed, due to different weather, Catalan toddlers were more likely to recognize the picture of a jacket than of a coat.

The prime-phase stimuli were the picture and audio label of either a chair or a jacket. The intervening-phase stimuli were the picture and audio label of either a chicken or car for half of the trials and a picture of a diamond or square checkerboard accompanied by a tone for the other half of the trials. In the test phase, the target stimuli were the pictures of either a table or a hat while the distractors pictures were either a balloon or a flower (see Annex 2).

Visual stimuli

The same pictures as in Chow et al. (2019) were used.

Auditory stimuli

The audio labels from Chow et al. (2019) were translated from English to Catalan. The same native female Catalan speaker as in Experiment 1 recorded the stimuli in a sound attenuated booth in a child-directed manner. The duration of the prime words was 770 milliseconds (ms) for the word "*cadira*" (chair) and 987 ms for the word "*jaqueta*" (jacket). The duration of the intervening word stimuli was 691 ms for "*cotxe*" (car) and 893 ms for "*gallina*" (chicken).

Eye-tracking data processing

Same as in Experiment 1a and 1b.

One of the stimuli (table) was shared between the lists of Experiment 1 and 2 and with a different role (distractor picture in

Experiment 1 and target picture in Experiment 2). As the list of Experiment 2 was presented in second for most of our participants, when it was the case, the trials containing the table were removed from the analysis to avoid any biased response. As a consequence, 11 toddlers who had at first a sufficient number of trials available for the analysis had to be excluded. After data pre-processing and the removing of the trials where the target was a table, 13 participants were excluded from the analysis. For the remaining participants, on average, 11 out of 16 trials from each participant were available for the analysis.

4.5.2 Results and Discussion

Toddlers were split into small and large vocabulary size groups according to their CDI receptive score in Catalan (median=80). The large vocabulary size group (N=12) understood a mean of 89 words (range=81-99) while the small vocabulary size group (N=13) understood a mean of 59 words (range=37-80). A Welch unequal variance t-test showed that the small vocabulary size group had a significantly lower CDI receptive score than the large vocabulary size group ($t(16.05)= 7.39$, $p<0.001$). For the test words used in the present experiment, on average, the large vocabulary size group was reported to understand 7.9 words (range=7-8) and the small vocabulary size group 5.6 words (range=1-8). These numbers are in the same range as for Chow et al. (2019).

The overall pattern of the fixation data is shown in Figure 4.5.

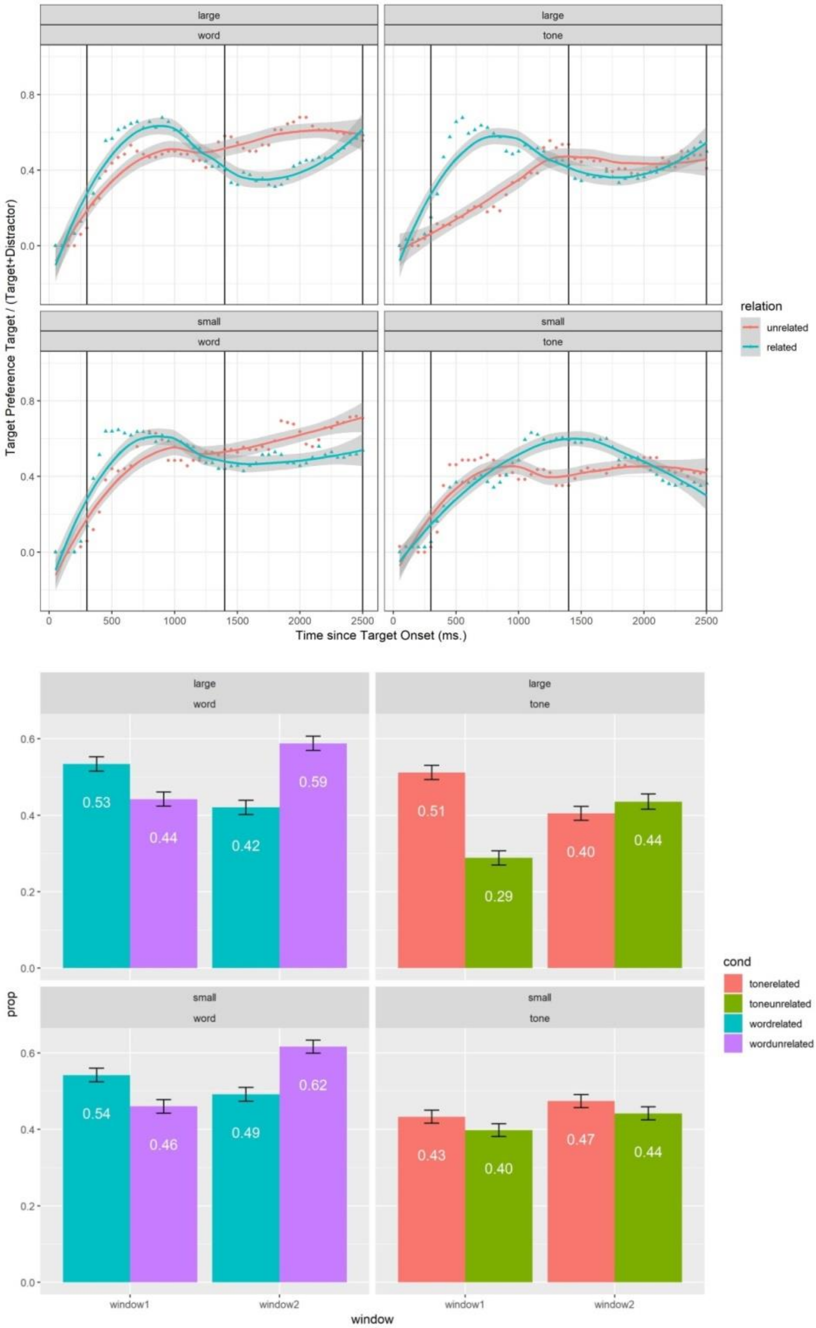

Figure 4.5 Monolingual toddlers' fixation data of Experiment 2a presented in time course (upper panel) and in aggregation (bottom panel) for each window of analysis (Window 1 (300-1400 ms) and Window 2 (1401-2500 ms) for each vocabulary size group (large: up and small: bottom) in each intervening condition (intervening word: right and intervening tone: left). Error bars are standard errors.

For each window of analysis, fixation data was entered into the same model as in Experiment 1a and 1b. However, in the Window 1, the model failed to converge. This absence of convergence was more likely due to the model being too complex to fit the dataset. Thus, data of the large and small vocabulary size groups was analysed separately with a simplified model.

Large vocabulary group (N=12)

For each window of analysis, the same model as in Chow et al. (2016) was used. Fixation data was entered into a binomial logistic mixed-effects model (R version 3.5.0, package lme4 version 1.1.20; function glmer) with only two fixed effects: Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated), and random effects of toddlers on the intercept.

Table 4.5 summarizes the results of the model in the Window 1.

Table 4.5. Results of Window 1 for the Large vocabulary Monolingual participant s (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	Estimates	SE	z	p
Intercept	-1.11	0.152	-7.28	<0.001*
Intervening stimulus: Word (baseline: Tone)	0.84	0.130	6.51	<0.001*
Prime type: Related (baseline: Unrelated)	1.11	0.128	8.68	<0.001*
Intervening stimulus: Word x Prime type: Related	-0.75	0.171	-4.38	<0.001*

In the Window 1, there was a significant main effect of intervening stimulus (Estimates=0.84; p<0.001) indicating that across both prime types, toddlers showed a significant increase in target preference in the intervening-word condition compared to the intervening-tone condition. There was also a significant main effect of prime type (Estimates= 1.11; $p<0.001$) indicating that across both intervening conditions, toddlers fixated more on the related-prime target than on the unrelated-prime target. Importantly, there was a significant interaction of intervening stimulus x prime type (Estimates=-0.75; $p<0.001$). Post-hoc model contrast with Bonferroni-corrected p-values showed that when the intervening stimulus was a word, toddlers fixated significantly more on the related-prime target than on the unrelated-prime target (Estimate=0.36; $z=3.23$; $p=0.003$). When the intervening stimulus was a tone, toddlers also fixated significantly more on the related-prime target than on the unrelated-prime target (Estimate=1.10; $z=8.68$; $p<0.001$).

In summary, in the Window 1, toddlers showed a facilitatory semantic priming effect in both the intervening-word and intervening-tone conditions.

Table 4.6 summarizes the results of the model in the Window 2.

Table 4.6. Results of Window 2 for the Large vocabulary Monolingual participants (1401-2500 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *$p<0.05$

Fixed Effects	Estimates	SE	z	p
Intercept	-0.29	0.15	-1.85	0.065
Intervening stimulus: Word (baseline: Tone)	0.67	0.11	5.85	<0.001*
Prime type: Related (baseline: Unrelated)	-0.15	0.11	-1.28	0.200
Intervening stimulus: Word x Prime type: Related	-0.61	0.16	-3.82	<0.001*

In the Window 2, there was no significant main effect of prime type (Estimate=-0.15; p=0.200) but there was a significant main effect of intervening stimulus (Estimate=0.67; p<0.001) indicating that across both prime types, toddlers showed a significant increase in target preference in the intervening-word condition compared to the intervening-tone condition. Importantly, there was a significant interaction of intervening stimulus x prime type (Estimates=-0.61; p<0.001). Post-hoc model contrast with Bonferroni-corrected p-values showed that when the intervening stimulus was a word, toddlers fixated significantly less on the related-prime target than on the unrelated-prime target (Estimate=-0.75; z=-6.78; p<0.001). When the intervening stimulus was a tone, toddlers looked similarly to the related-prime and unrelated-prime targets (Estimate=-0.15; z=-1.28; p=0.4). In summary, in the Window 2, toddlers showed backward semantic inhibition.

Summarizing for the large vocabulary size group, in the intervening word condition, toddlers showed a facilitatory semantic priming effect in the Window 1 and backward semantic inhibition in the Window 2. In the intervening tone condition, they showed facilitatory semantic priming effect in the Window 1 but no effects the Window 2. These results replicate the pattern found by Chow et al. (2019) for which toddlers with large vocabulary size showed backward semantic inhibition in the Window 2 of the intervening word condition and facilitatory semantic priming effect in the Window 1 of the intervening tone condition. Contrary to Chow et al. (2019), we also found a facilitatory semantic priming effect in the Window 1 of the intervening word condition. However the size of this effect was smaller in the intervening word condition than in the intervening tone condition (as shown by the significant interaction). One potential explanation could be that the intervening word already inhibited the semantic facilitation in the first window.

Small vocabulary group (N=13)

Table 4.7 summarizes the results of the model in the Window 1.

Table 4.7 Results of Window 1 for the Small vocabulary Monolingual participants (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	Estimates	SE	z	p
Intercept	-0.41	0.12	-3.32	<0.001*
Intervening stimulus: Word (baseline: Tone)	0.27	0.11	2.51	0.012*
Prime type: Related (baseline: Unrelated)	0.16	0.10	1.58	0.115
Intervening stimulus: Word x Prime type: Related	0.21	0.15	1.42	0.155

In the Window 1, there was no significant main effect of prime type (Estimate=0.16; p=0.115) but there was a significant main effect of intervening stimulus (Estimate=0.27; p=0.012) indicating that across both prime types, toddlers showed a significant increase in target preference in the intervening-word condition compared to the intervening-tone condition. There was no significant interaction of intervening stimulus x prime type (Estimate=0.21; p=0.155). In summary, in the Window 1, no facilitatory or inhibitory effects were observed for both intervening conditions.

Table 4.8 summarizes the results of the model in the Window 2.

Table 4.8. Results of Window 2 for the Small vocabulary Monolingual participants (1401-2500 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	-0.27	0.14	-1.84	0.066
Intervening stimulus: Word (baseline: Tone)	0.73	0.10	7.04	<0.001*
Prime type: Related (baseline: Unrelated)	0.13	0.10	1.27	0.203
Intervening stimulus: Word x Prime type: Related	-0.64	0.15	-4.38	<0.001*

In the Window 2, there was no significant main effect of prime type (Estimate=0.13, p=0.203) but there was a significant main effect of intervening stimulus (Estimate=0.73; p<0.001) indicating that across both prime types, toddlers showed a significant increase in target preference in the intervening-word condition. Importantly, there was a significant interaction of intervening stimulus x prime type (Estimate=-0.64; p=0.001). Post-hoc model contrast with Bonferroni-corrected p-values showed that when the intervening stimulus was a word, toddlers fixated significantly less on the related-prime target than on the unrelated-prime target (Estimate=-0.51; z=-4.84; p<0.001). When the intervening stimulus was a tone, toddlers looked similarly to the target picture regardless of its semantic relation to the prime (Estimate=0.13; z=-1.27; p=0.406). In sum, in the Window 2, toddlers showed backward semantic inhibition when the intervening stimulus was a word.

Summarizing for the small vocabulary size group, in the intervening word condition, toddlers showed backward semantic inhibition in the Window 2. In the intervening tone condition, they did not show any facilitatory or inhibitory effects in any window of analysis.

These results do not replicate the pattern found by Chow et al. (2019) for which toddlers with small vocabulary size showed a facilitatory semantic effect in the first window of the intervening tone condition.

Taken together, the results of Experiment 2a replicate the pattern found by Chow et al. (2019) for the toddlers in the large vocabulary size group but not in the small vocabulary size group.
We present next the results of the bilinguals that were collected in parallel.

4.6 Experiment 2b

4.6.1 Methods

Participants

Fifteen 24 month-old Spanish-Catalan bilingual (mean age=24 month 18 days; range=23 months 22 days – 25 months 29 days; 7 males) toddlers have been tested and included in the analysis. Nine additional toddlers were tested but excluded from the analysis for the following reasons: technical problem (N=1), crying or fussiness (N=3), bad quality of eye-tracking data (N=2), and parental interference (N=2). Following the error in the experimental design, 5 additional toddlers included at first had to be removed from the analysis.

As in Experiment 1b, all participants were exposed to both Catalan and Spanish on a daily basis, the exposition to their main language (Catalan) being up to 75% of the time. The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). All parents signed informed consent for their infants to participate in this study.

Stimuli, Apparatus and Procedure

Same as in Experiment 2a

Eye-tracking data processing

Same as in Experiment 2a

After data pre-processing and the exclusion of the trials where the table was a target, 5 participants had to be excluded from the analysis. On average, 10 out of 16 trials from each participant were available for the analysis.

4.6.2 Results and Discussion

As in Experiment 1b, toddlers were separated into large and small vocabulary size groups according to their CDI receptive concept scores (median=84). The large vocabulary size group (N=7) understood a mean of 93 words (range=85-99), while the small vocabulary size group (N=8) understood a mean of 73 words (range=38-84). For the test words, all toddlers in the large vocabulary group were reported to understand the 8 test words while toddlers in the small vocabulary size group were reported to understand on average 7.1 words (range=4-8). These numbers are similar to the ones reported for the monolinguals in Experiment 1a for the large vocabulary size group (8 vs. 7.9) but are higher for the small vocabulary size group (7.1 vs. 5.6). This may be due to the fact that only 24 month-olds were tested in this experiment and no 18 month-olds (who usually know less words).

The overall pattern of the fixation data is shown in Figure 4.6. To allow for comparison with the monolingual group in Experiment 2a, the large and small vocabulary size groups were analysed separately and fixation data of each window of analysis was entered in the same model.

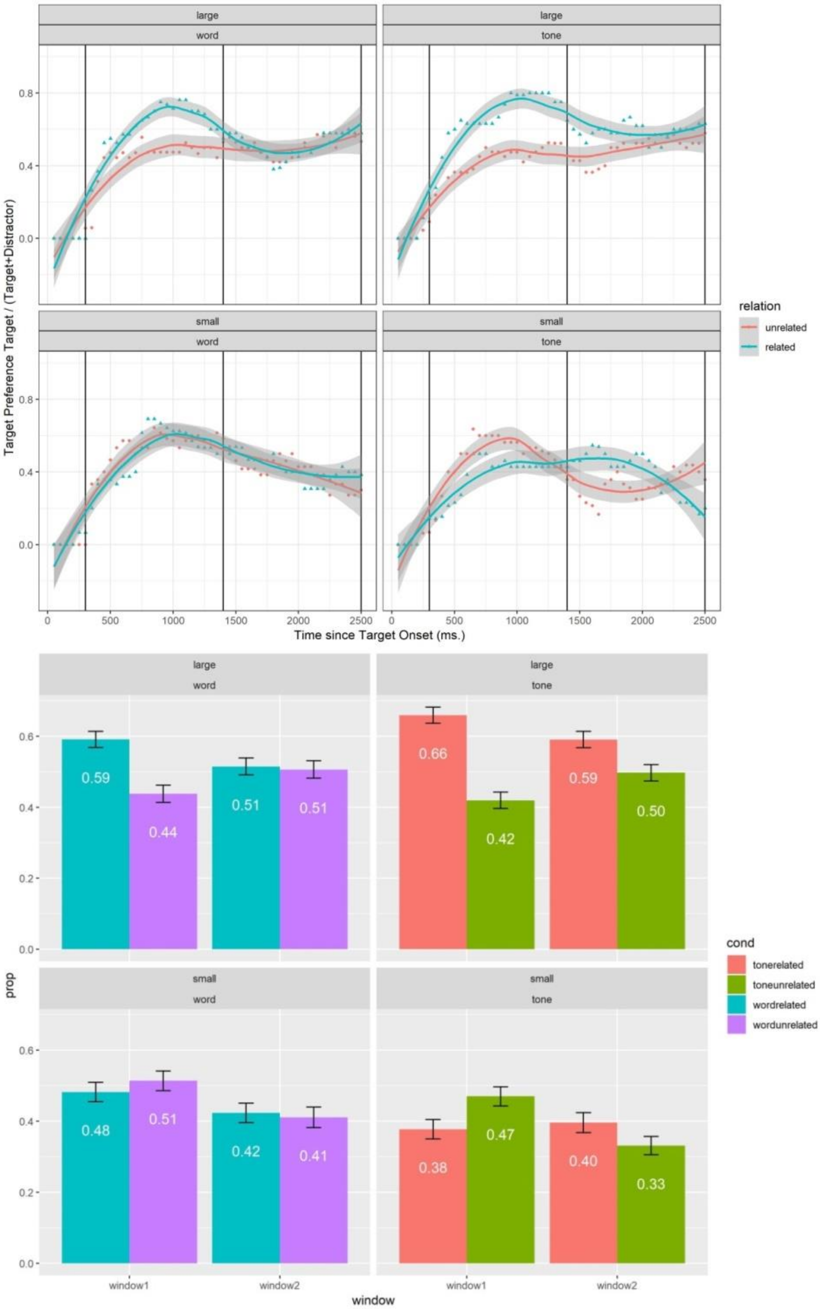

Figure 4.6. Bilingual toddlers' fixation data of Experiment 2b presented in time course (upper panel) and in aggregation (bottom panel) for each window of analysis (Window 1 (300-1400 ms) and Window 2 (1401-2500 ms)) for each vocabulary size group (large: up and small: bottom) in each intervening condition (intervening word: right and intervening tone: left). Error bars are standard errors.

<u>Large vocabulary size group (N=7)</u>

Table 4.9 summarizes the results of the model for the Window 1.

Table 4.9. Results of Window 1 for the Large vocabulary Bilingual participants (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	Estimates	SE	z	p
Intercept	-0.34	0.13	-2.60	<0.01*
Intervening stimulus: Word (baseline: Tone)	0.07	0.14	0.49	0.622
Prime type: Related (baseline: Unrelated)	1.07	0.14	7.44	<0.001*
Intervening stimulus: Word x Prime type: Related	-0.40	0.21	-1.91	0.056

In the Window 1, there was no significant main effect of intervening stimulus (Estimate=0.07, p=0.622) but there was a significant main effect of prime type (Estimate=1.07; p<0.001) indicating that across both intervening conditions, toddlers fixated more on the related-prime target than on the unrelated-prime target. Importantly, there was a marginal interaction of intervening stimulus x prime type (Estimates=-0.40; p=0.056) indicating a tendency of a bigger size effect in the intervening tone condition compared to the intervening word condition. Taken together, in the Window 1, toddlers showed a facilitatory semantic priming effect in both the intervening-word and intervening-tone conditions.

Table 4.10 summarizes the results of the model in the Window 2.

Table 4.10. Results of Window 2 for the Large vocabulary Bilingual participants (1401-2500 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *$p<0.05$

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	-0.05	0.16	-0.31	0.757
Intervening stimulus: Word (baseline: Tone)	0.04	0.14	0.26	0.795
Prime type: Related (baseline: Unrelated)	0.39	0.13	2.95	0.003*
Intervening stimulus: Word x Prime type: Related	-0.41	0.19	-2.13	0.033*

In the Window 2, there was again no significant main effect of intervening stimulus (Estimate=0.04, p=0.795) but there was a significant main effect of prime type (Estimate=0.39; p=0.003) indicating that across both intervening conditions, toddlers fixated more on the related-prime target than on the unrelated-prime target. Importantly, there was a significant interaction of intervening stimulus x prime type (Estimate=-0.41; p=0.033). Post-hoc model contrast with Bonferroni-corrected p-values showed that, when the intervening stimulus was a word, toddlers looked similarly at the related-prime and unrelated-prime targets (Estimate=-0.02; z=-1.45; p=1). When the intervening stimulus was a tone, toddlers fixated significantly more on the related-prime target than on the unrelated-prime target (Estimate=-0.39; z=2.94; p=0.006). Taken together, in the Window 2, toddlers showed facilitatory semantic priming effect in the intervening tone condition.

Summarizing for the bilingual large vocabulary group, in the intervening word condition, toddlers showed facilitatory semantic priming effect in the Window 1 and no effect in the Window 2. In the intervening tone condition, they showed facilitatory semantic priming effect in both windows of analysis. These results partially replicate the pattern found with the monolinguals in Experiment 1a as they also showed a late backward semantic inhibition in the intervening word condition in addition to the facilitatory semantic priming effect. This difference may be due to the lower number of participants for the bilinguals than for the monolinguals. Even if it was marginal (p=0.056), it is interesting to note that in the Window 1, we found the same interaction of intervening stimulus x prime type as for the monolinguals. This interaction suggesting an inhibition by the intervening word of the semantic facilitation, it is possible that a backward semantic inhibition may appear when adding more participants.

<u>Small vocabulary size group (N=8)</u>

Table 4.11 summarizes the results of the model in the Window 1.

Table 4.11. Results of Window 1 for the Small vocabulary Bilingual participants (300-1400 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	Estimates	SE	z	p
Intercept	-0.17	0.18	-0.95	0.344
Intervening stimulus: Word (baseline: Tone)	0.22	0.17	1.33	0.185
Prime type: Related (baseline: Unrelated)	-0.40	0.17	-2.33	0.020*
Intervening stimulus: Word x Prime type: Related	0.26	0.24	1.10	0.272

In the Window 1, there was no significant main effect of intervening stimulus (Estimate=0.22, p=0.185). There was a significant main effect of prime type (Estimate=-0.40; p=0.02) indicating that across both intervening conditions, toddlers fixated less on the related-prime target than on the unrelated-prime one. However, there was no significant interaction of intervening stimulus x prime type (Estimate=0.26, p=0.272). In summary, in the Window 1, toddlers showed general preference for the unrelated-prime target in both intervening stimulus conditions.

Table 4.12 summarizes the results of the model for the Window 2.

Table 4.12. Results of Window 2 for the Small vocabulary Bilingual participants (1401-2500 ms.). Growth curve analysis of target probability with fixed effects of Intervening stimulus (Word vs. Tone) and Prime Type (Related vs. Unrelated) *p<0.05

Fixed Effects	**Estimates**	**SE**	**z**	**p**
Intercept	-0.75	0.20	-3.81	<0.001*
Intervening stimulus: Word (baseline: Tone)	0.36	0.17	2.07	0.039*
Prime type: Related (baseline: Unrelated)	0.20	0.17	1.14	0.256
Intervening stimulus: Word x Prime type: Related	-0.15	0.24	-0.611	0.541

In the Window 2, there was no significant main effect of prime type (Estimate=0.20, p=0.256) but there was a significant main effect of intervening stimulus (Estimate=0.36; p=0.039) indicating that across both prime types, toddlers showed a significant increase in target preference in the intervening-word condition compared to the intervening-tone condition. The interaction of intervening stimulus and prime type was not significant (Estimate=-0.15, p=0541). In sum, in Window 2, no significant facilitatory or inhibitory effects were observed.

Summarizing, for the bilingual small vocabulary size group, for both intervening stimulus conditions, toddlers showed a general preference for the unrelated-prime target in the Window 1 and no significant effect in the Window 2.

Taken together, the results of Experiment 2b partially replicate the pattern of results of the monolinguals in Experiment 2a for the bilingual toddlers in the large vocabulary size group but not for the bilingual toddlers in the small vocabulary size group.

Discussion

First of all, we acknowledge that the sample size of the present experiment was far from sufficient. As described in the discussion of the experiment 1, data collection started quite late, once we realised we were not replicating the original results.

In general, and contrary to Experiment 1a and 1b, Experiment 2a and 2b replicated the pattern of results found by Chow et al. (2019) for both the monolingual and bilingual toddlers with the large vocabulary size (although in the case of the bilinguals, it was only a partial replication). However, we are not replicating the pattern for the small vocabulary size groups, both with the monolingual and bilingual participants. Such conclusions, however, have to be taken with caution because, as just said, our sample size was very small and the stimuli did not follow the same restrictions as Chow et al's. In particular, the related prime and the intervening stimulus did not share their onset ("**c**adira/**g**allina" and "**j**aqueta/**c**otxe", while in the original experiment they were "**ch**air/**ch**icken" and "**c**oat/**c**ar").

4.7 General discussion

In the present research, we wanted to explore the emergence of semantic inhibitory effects in bilingual toddlers by investigating the backward semantic inhibition. To do so, we replicated the design by Chow et al. (2019) and adapted the original stimuli from English to Catalan. As in Chow et al. (2019), participants were separated into large and small vocabulary size groups. In a first group of experiments, our results failed to replicate the pattern of results found by Chow et al. (2019) with both Catalan monolinguals (Experiment 1a) and Spanish-Catalan bilinguals (Experiment 1b). In a second group of experiments, participants were tested with the same set of stimuli as Chow et al. (2019). Our results partially replicated the results by Chow et al. (2019) with the monolingual and bilingual participants for the large vocabulary size group but not for the small vocabulary size group.

We will first discuss the results of Experiments 1a and 1b (see Table 4.13 for a general summary of the time course results).

In Experiment 1a, we tested a group of Catalan monolingual toddlers to validate the stimuli used with the Spanish-Catalan bilinguals in Experiment 1b. However, the results only showed a general preference for the unrelated-prime target, regardless of the intervening stimulus and vocabulary size. In Experiment 1b, an effect of intervening stimulus was found for the bilinguals with large vocabulary size who showed backward semantic inhibition but not for the bilinguals with small vocabulary size who only showed a general preference for the unrelated-prime target. Taken together, this complex pattern of results does not replicate the original study by Chow et al. (2019).

As mentioned before, this lack of replication in Experiments 1a and 1b may be due to our prime and target stimuli not having equivalent strong semantic relatedness as in Chow et al. (2019). We decided to use words as different as possible in the two languages of the child (mostly non-cognates), something that restricted the potential candidates. Additionally, following the design of Chow et al. (2019), prime and intervening words shared the same phonological onset, constraining even more the available stimulus. As a matter of fact, when asked about the experimental words, some parents reported that their infants did not know the picture of the soap bar, as they used gel (although the picture contained bubbles). It is possible that lack of proper recognition of the stimuli by some children prevented switching between semantic categories, and therefore the emergence of backward semantic inhibition.

The absence of replication could also be due to our participants knowing less experimental words than the participants in Chow et al.'s studies. However, as shown in the Table 4.14, our monolingual participants knew an equivalent number of experimental words when compared to the participants tested in Chow et al. (2016, 2019). Similarly, Table 4.16 shows that the bilingual participants knew an equivalent number of experimental words as the monolinguals when considering their concept score. Thus, the lack of replication in the present research does not seem to be due to our participants knowing less experimental words.

In Experiments 2a and 2b, we tested both Catalan monolinguals and Spanish-Catalan bilinguals with the same set of stimuli as Chow et al. (2019). For both linguistic groups, we replicated the results found by Chow et al. (2019) for the participants with large vocabulary size but not for the participants with small vocabulary size. However, the small sample size in both experiments prevents us from drawing firm conclusions. As mentioned before, the stimuli in Experiments 2a and 2b did not follow the same restrictions as in Experiment 1 as they were not controlled for cognateness and the prime and intervening stimulus did not share the same onset.

Putting the small sample size aside, the findings of backward semantic inhibition with the same stimuli as Chow et al. (2019) can be taken as suggesting that the stronger semantic relationship between the prime and target had a critical role in the lack of effects in experiment 1.

Regarding the bilinguals, in both Experiment 1b and 2b, participants were separated into large and small vocabulary size groups according to their conceptual vocabulary. This choice was motivated by the fact that previous research has shown that bilinguals tend to know fewer words in each of their languages when compared to monolinguals, even when assessed in their dominant language (Hoff et al., 2012; Hoff, Rumiche, Burridge, Ribot, & Welsh, 2014). Therefore, some bilinguals might not know the word in the test language, but in their second language. Although it would be interesting to run the same analysis on the vocabulary scores in Catalan, we do not anticipate obtaining significant differences. First, there is a strong correlation between conceptual vocabulary and vocabulary in the dominant language, thus, the median split would result in virtually the same large and small vocabulary. Second, it is unknown if familiarity with the visual stimuli would be enough to elicit the effect, and knowing the word in the non-target language implies familiarity with the semantic category.

In summary the results of the present research did not allow us to draw strong conclusions on the emergence of inhibitory effects in bilingual toddlers. More analysis of the present data is needed as we did not have the time to perform the analysis by splitting the bilingual participants according to their vocabulary score in the target language. It is also important to test more participants with the same stimuli as Chow et al. (2019) in order to confirm if the replication we found for the participants with large vocabulary is a robust effect.

Finally, new studies with new materials are also needed to address the question of backward semantic inhibition in bilingual toddlers.

Table 4.13 Summary of the results found by Chow et al. (2016, 2019) and in the present research in each window of analysis of the intervening-word and intervening-tone conditions for the large and small vocabulary size groups.

	Large vocabulary size group			
	Intervening word condition		**Intervening tone condition**	
	Window 1	**Window 2**	**Window 1**	**Window 2**
Chow et al. (2016)	No effect	BSI	No effect	Facilitation
Chow et al. (2018)	No effect	BSI	Facilitation	No effect
Monolinguals (1a)	No effect	Preference for unrelated target	No effect	Preference for unrelated target
Bilinguals (1b)	No effect	BSI	No effect	No effect
Monolinguals (2a)	Facilitation -	BSI	Facilitation +	No effect
Bilinguals (2b)	Facilitation	No effect	Facilitation	Facilitation

	Small vocabulary size group			
	Intervening word condition		**Intervening tone condition**	
	Window 1	**Window 2**	**Window 1**	**Window 2**
Chow et al. (2018)	No effect	No effect	Facilitation	No effect
Monolinguals (1a)	No effect	Preference for unrelated target	No effect	Preference for unrelated target
Bilinguals (1b)	No effect	Preference for unrelated target	No effect	No effect
Monolinguals (2a)	No effect	BSI	No effect	No effect
Bilinguals (2b)	Preference for unrelated target	No effect	Preference for unrelated target	No effect

Table 4.14 Detail of the mean vocabulary scores obtained by the monolinguals participants in Chow et al. (2016, 2019) and in the present research for the experimental words.

	Large vocabulary size group	Small vocabulary size group
Chow et al. (2016)	29 toddlers: 8 words 6 toddlers: 4 to 7 words	NA
Chow et al. (2018)	7.5	5.1
Monolinguals (1a)	7.3	4.5
Monolinguals (2a)	7.9	5.6

Table 4.15 Detail of the mean vocabulary scores obtained by the monolinguals participants in the present research for the experimental words in Catalan and in Spanish.

	Large vocabulary size group		Small vocabulary size group	
	Catalan	**Spanish**	**Catalan**	**Spanish**
Monolinguals (1a)	7.3	1.3 (*)	4.5	1.5 (**)
Monolinguals (2a)	7.9	5 (***)	5.6	2.5 (****)

(*) data from 15 babies out of 33 (the others were 100% Catalan); (**) data from 17 babies out of 33; (***) data from 5 babies out of 12; (****) data from 4 babies out 13

Table 4.16 Detail of the mean vocabulary scores obtained by the bilingual participants in the present research for the experimental words in Catalan and Spanish and the corresponding concept score.

	Large vocabulary size group			Small vocabulary size group		
	Catalan	**Spanish**	**Concept score**	**Catalan**	**Spanish**	**Concept score**
Bilinguals (1b)	7.2	6.6	7.7	4.9	3.5	5.8
Bilinguals (2b)	8	7.1	8	6.1	4.8	7.1

5. DISCUSSION

In the present dissertation we compared monolingual and bilingual language acquisition by addressing two main topics in early bilingual language acquisition: the establishment of the phoneme system and the establishment of the lexico-semantic system.

In Chapters 2 and 3, we investigated the acquisition of a phoneme system by assessing the possible influences of word-level information on phonetic learning in both monolinguals and bilinguals. We tested both adults (Chapter 2) and 8-month-old infants (Chapter 3).

In Chapter 4, we explored the development of the lexico-semantic semantic system by investigating the backward semantic inhibition in monolingual and bilingual 18 to 24-month-old toddlers.

In this section of the dissertation, we will first review the main findings of the studies. Then we will discuss our results in the context of the current investigation in the field and suggest some future directions.

5.1 Summary of the findings

5.1.1 Acquisition of a phoneme system

In the Chapters 2 and 3 we wanted to assess if top-down information was processed in an equivalent way by monolingual and bilingual individuals. The motivation for such research stems in the complex pattern of results obtained by the studies with 8-month-old Spanish-Catalan bilinguals concerning the discrimination of some native contrasts. These studies have shown a specific developmental trajectory for the bilinguals compared to the monolinguals (Bosch & Sebastian-Galles, 2003; Sebastian-Galles & Bosch, 2009) or not (Albareda-Castellot, Pons & Sebastian-Galles, 2011).

Feldman et al. (2013) have shown that, contrary to the assumption that meaning is required to constrain phonetic learning through minimal pairs, both adults and infants are sensitive to word-level information not related to meaning when learning a native phonetic contrast.

In the present research, we addressed the question of the Spanish-Catalan bilingual perceptual reorganization from a different perspective from the previous studies by testing the discrimination of a non-native contrast in both Spanish and Catalan monolinguals and Spanish-Catalan bilinguals. We replicated the study by Feldman et al. (2013) to assess the sensitivity to word-level information when learning a non-native British English contrast and if simultaneous bilingual exposure had an influence on how such information is used.

In Chapter 2, as Feldman et al. (2013), we tested first a group of adult participants with a phonetic category learning task. Participants were familiarized to pseudo-words that included or not minimal pairs and then tested on their discrimination of the non-native contrast. In Experiment 1, our results replicated the pattern found by Feldman et al., (2013) for the monolingual participants: they showed sensitivity to word-level information as their discrimination performance was better after familiarization to pseudo-words *not* including minimal pairs (henceforth non-minimal pairs) than after familiarisation to pseudo-words containing minimal pairs (henceforth minimal pairs). In Experiment 2, the simultaneous bilinguals behaved differently as they showed good discrimination performance regardless of the type of familiarisation. When comparing the results between monolinguals and simultaneous bilinguals, the latter showed better discrimination of the non-native contrast after exposure to minimal pairs.

In the last experiment of Chapter 2 (Experiment 3), we assessed our participants' baseline discrimination of the non-native contrast. Unexpectedly, both groups of participants showed good baseline discrimination, though it was better for the simultaneous bilinguals compared to the monolinguals.

For the monolinguals, the results of the Experiment 3 challenged Feldman et al's explanation of the better performance of participants exposed to non-minimal pairs when compared to those exposed to minimal pairs. According to Feldman and co-workers, exposure to non-minimal pairs facilitated discrimination. However, our results indicate that the difference in performance for the monolinguals in Experiment 1 is due to the fact that exposure to minimal pairs hindered discrimination. This result (not tested by Feldman et al.) constitutes an original contribution of our investigation.

Such explanation, however, would be restricted to monolinguals, as surprisingly for bilinguals, both types of familiarisation hindered discrimination.

In Chapter 3, we tested 8 month-old participants with the Head-turn Preference procedure and the same non-native contrast as for the adults in Chapter 2. As the adults, participants were first familiarized with pseudo-words containing or not minimal pairs and then tested with trials containing one of the non-native vowels (2 types of Non-Alternating trials) and trials containing both non-native vowels (Alternating trials).

Our results showed that monolinguals and bilinguals were not sensitive to word-level information as both linguistic groups did not behave differently after being familiarized with pseudo-words containing minimal pairs or not. However, both populations showed a contrastive pattern of discrimination: monolingual infants discriminated the non-native contrast while bilinguals did not.

Summarising, our results suggest that adults (monolinguals and simultaneous bilinguals) showed a difference in their sensitivity to word-level information not related to meaning when learning a non-native contrast.

The results of 8-month-old infants were in clear contrast with adults'. Contrary to adult peers, monolingual and bilingual infants did not show sensitivity to word-level information. Moreover, only monolinguals showed discrimination. The conclusions for the infant group are still provisional as we have planned to clarify the monolinguals' pattern of results with two different studies: first by assessing the infants' baseline discrimination of the non-native contrast and second, by extending the familiarization period to the non-native contrast.

5.1.2 Establishment of the semantic system

In chapter 4, we investigated the emergence of inhibitory effects in the bilingual lexicon. This study was motivated by the fact that the investigation of the semantic system in bilingual toddlers remains scarce and the results do not converge across studies. Previous studies of semantic priming in monolinguals have shown forward inhibitory effects of an unrelated prime on target recognition in both monolingual (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009) and bilingual (Singh, 2014; Jardak & Byers-Heinlein, 2019) toddlers. Backward inhibitory effects of an unrelated prime on target recognition (or backward semantic inhibition) have been also reported in monolingual toddlers (Chow et al., 2016, 2019). Relevant to our goals, in such studies the appearance of these inhibitory effects was modulated by vocabulary size. This last finding constituted an opportunity to identify the type of information responsible of the inhibitory effects (words or concepts). Originally we intended to investigate which of the two ways of measuring bilinguals' word knowledge better accounted their behaviour: by considering the word forms they know in the test language or by considering their "conceptual vocabulary" (number of concepts for which bilinguals know at least one word). The original plan was to validate the procedure and materials by replicating Chow et al. (2019) with Catalan monolingual toddlers and then to test a sufficient large number of bilinguals to be able to disentangle the two types of vocabularies.

We adapted the experimental paradigm by Chow et al. (2019) from English to Catalan and tested both Spanish and Catalan monolinguals and Spanish-Catalan bilinguals from 18 to 24 month of age. As planned, to investigate the modulation of the vocabulary size on the appearance of inhibitory effects, participants were split into large and small vocabulary size groups. As bilinguals know less word in each of their language than monolinguals (Hoff et al., 2012) but may know one word in the other language, bilinguals were first split into large and small vocabulary size groups according to their conceptual vocabulary. In this way, bilinguals' vocabulary size would be comparable to monolinguals', as the conceptual vocabulary in bilinguals is similar to monolinguals' vocabulary.

The results of our first study failed to replicate the pattern of results found by Chow et al. (2019) with both Catalan monolinguals and Spanish-Catalan bilinguals. We hypothesised that the lack of effects might be due to properties of the stimuli used. In a second set of studies, we tested another group of monolinguals and bilinguals with the same stimuli as Chow et al. (2019). Here we partially replicated Chow et al. (2019) with the monolingual and bilingual participants for the large vocabulary size group but not for the small vocabulary size groups.

Taken together, the complexity of the results in the experiments reported in chapter 4, together with several methodological limitations did not allowed us to conclude on the emergence of inhibitory effects in the bilingual lexicon and if this effect was modulated by the vocabulary size.

5.2 General Discussion

In chapter 2, we found that adult monolinguals were sensitive to word-level information not related to meaning when learning a non-native contrast. This result replicated the pattern found by Feldman et al. (2013) and extended the influence of word-level information to the case of a second-language (L2) contrast. However, this result is not line with the predictions of actual models of L2 sound learning in adults (SLM, Flege, 1995; PAM-L2, Best & Tyler, 2007; L2LP, Escudero, 2009). As we reviewed, these models based their predictions for L2 sound learning mainly on the use of bottom-up/distributional information. They also consider possible top-down influences from the lexicon, but only through the use of meaning (PAM-L2, Best & Tyler, 2007) or minimal pairs (L2LP revised, Leussen & Escudero, 2012). By showing that word-level information not related to meaning can also influence L2 sound learning, our results argue for more interactive models of L2-sound learning in adults that considers the influence of the lexicon through word forms as well as meaning.

An original contribution of the chapter 2 is that exposure to minimal pairs hindered discrimination. This was not exactly in line with the prediction by Feldman et al. (2013) that hypothesized that exposure to non-minimal pairs facilitate discrimination. This different result may be due to our test contrast being easier to discriminate than the one used by Feldman et al. (2013). Consequently, in our research the exposure to non-minimal pairs may not have been informative for our participants. In contrast, the exposure to minimal pairs that informed that two sounds may belong to one category may have had an impact on our participants' discrimination abilities (impact that may not have been possible for the participants tested by Feldman et al. (2013), as their contrast was already difficult to discriminate). These results suggest that exposure to minimal pairs or non-minimal pairs influence the discrimination of both native and non-native contrasts in adults, their actual impact depending of the difficulty of the contrast tested. Testing these hypothesis experimentally may prove to be quite complex, as shown by the quite good performance of our participants in spite of previous literature (Escudero & Chládková, 2010; Flege & MacKay, 2004). These studies suggested that this was a quite difficult contrast for Spanish and Italian natives (and therefore Catalan, given the similarities between Catalan vowel system and Italian one). One possible way of tackling the problem is through computational modelling. It should be relatively easy to assess initial performance of some contrasts and then feed the model to check the predictions it would make. Such predictions would be then tested experimentally. This is a research line we are starting to explore with collaboration of other members of the Speech Acquisition and Perception group.

Minimal pairs have been extensively used in adult studies to teach new L2 contrasts (Jamieson & Morosan, 1986; Kondaurova & Francis, 2010; Francis & Nusbaum, 2002); our results suggest that they should be used with more caution. They also open new possibilities of L2 sounds training in adults.

In the same chapter 2, we found that simultaneous bilinguals differed from monolinguals on their sensitivity to word-level information not related to meaning. Crucially, in this study monolingual participants were actually sequential bilinguals who had been exposed to their second language after 3 years of age and who are highly competent in their L2. These results thus suggest that the changes induced by bilingual exposure take place very early in life. This finding contrasts the prediction done by the PRIMIR model (Curtin, Byers-Heinlein & Werker, 2011) that monolingual and bilingual infants do not differ when acquiring their phonetic categories.

Even if the procedure is different, these results echoes with previous research in Spanish-Catalan adults who found divergent discrimination abilities for native contrasts in simultaneous and sequential bilinguals (Pallier, Bosch & Sebastian-Galles, 1997; Sebastian-Galles & Soto-Faraco, 1999; Pallier, Colome & Sebastian-Galles, 2001; Bosch, Costa and Sebastian-Galles, 2000; Sebastian-Galles and Baus, 2005; Sebastian-Galles, Echeverría & Bosch, 2005; Sebastian-Galles et al., 2006). In future research it would be interesting to assess in the same population of bilinguals the influence of word-level information in the case of a very difficult native contrast, such as the Catalan /e-ɛ/ contrast.

The results with the simultaneous bilinguals have raised several possibilities to account for their different pattern of results. Their good discrimination of the non-native contrast may be due to higher sensitivity to sub-phonemic/acoustic information. Such sensitivity has been reported for both bilingual infants and adults (Elman, Diehl & Buchwald, 1977; Ju & Luce, 2004; Mattock, Polka et al. 2010; Fennell & Byers-Heinlein, 2014).

Then, the fact that simultaneous bilinguals discriminated better the non-native contrast compared to the monolinguals after familiarization to minimal pairs could be reflecting greater attention to word context information. This could have been induced by the Spanish-Catalan speech stream that contains a high number of cognate words differing mainly on their vowel sounds consequently increasing the number of minimal pairs. However, it cannot be excluded that this effect may also be due to sole bilingual exposition. One way to verify this possibility would be to test bilingual participants exposed to a smaller amount of minimal pairs/cognates in the speech stream such as Spanish-Basque bilinguals.

Finally, the results of the baseline discrimination score in simultaneous bilinguals have indicated that exposure to both minimal pairs and non-minimal pairs hindered discrimination. This was an unexpected result as simultaneous bilinguals showed good discrimination in the Experiment 2. Investigations with more difficult L2 contrasts may help clarify this puzzling result.

In summary, the complex pattern of results with the simultaneous bilinguals did not allow us to account for their results.

The results of the chapter 3 suggested that both monolingual and bilingual infants are not sensitive to word-level information not related to meaning.

For the monolinguals, this result does not replicate the pattern found by Feldman et al. (2013) who found sensitivity to such information in 8 month-old infants learning a native contrast. Moreover, our adult data in Chapter 2 also suggested sensitivity to word-level information. It is possible that in the case of a non-native contrast infants may develop sensitivity to word-level information at an older age. Thiessen (2007) as well as Thiessen and Yee (2010) have reported sensitivity to word-level information in 15 month-olds. Testing older participants may help clarify this question. Another possibility for the lack of sensitivity in monolinguals could be linked to the short familiarization that may have prevented the appearance of an effect. Other studies with longer familiarization may help ascertain this hypothesis.

For the bilinguals, the lack of sensitivity to word-level information parallels the results with the monolinguals. This result suggests again a possible absence of sensitivity to word-level information during early infancy concerning the discrimination of a non-native contrast. However, contrary to the monolinguals, they did not discriminate the non-native contrast (see next paragraph). This lack of discrimination of the non-native contrast may have masked the possible influence of word-level information. Like suggested for the monolinguals, testing older infants may help confirm if sensitivity to word-level information may appear later in development.

The difference in discrimination abilities between the monolinguals and bilinguals was an unexpected result. The fact that monolinguals showed discrimination of the non-native contrast is in line with the adult data in chapter 2, indicating parallel discrimination abilities between infants and adults. This same pattern has been reported by Polka and Bohn (1996). In their study, both adults and 6- to 8-month-olds showed non-native contrast discrimination. Bosch and Sebastian-Galles (2003) also found no discrimination of a non-native contrast in 8-month-old Spanish monolinguals that is difficult to perceive for their adult peers. Another possibility for this pattern may be due that at this age, the perceptual reorganization is not completely finished for the vowel sounds as suggested by Feldman et al. (2013). Factors like frequency of appearance have been shown to modulate the speed with which a phonetic contrast is established (Anderson, Morgan & White, 2003). Here we tested a non-native phoneme contrast. The fact that perception of non-native contrasts depends on the relative distribution of L1 and L2 sounds and that L1 sounds may not be fully established at this age, makes very difficult to provide a specific hypothesis for our finding of discrimination. As suggested for adults, one potential line of research is to perform a computational modeling where frequency of appearance of the different phonemes (and possibly word contexts) should be introduced in the model to better model infants' input.

The absence of discrimination in bilinguals was surprising and contrasted with the results of the adult data in Chapter 2 who showed good discrimination for the same contrast. Again, and as for the adult data, this result is not in line with the prediction of the PRIMIR model that considers that monolinguals and bilinguals do not differ when acquiring their phonetic categories. However, this result is in line with the previous investigations reviewed in the Introduction of the present dissertation that showed no discrimination of a native contrast at the same age (Bosch & Sebastian-Galles, 2003; Sebastian-Galles & Bosch, 2009). Another possibility for this lack of discrimination could be linked to the experimental paradigm. Albareda-Castellot et al. (2011) reported discrimination of a native contrast in Spanish-Catalan bilinguals that was not discriminated by the same participants with a different procedure. Testing bilingual participants with a different paradigm may shed some light on the present negative result. To the best of our knowledge there is no published study investigating the time-course of perceptual reorganization for non-native contrasts in bilinguals, even less of training of such contrasts in this population. This lack of evidence together with the negative results makes it very difficult to make specific predictions. As suggested for the monolinguals, performing computational modeling is a possible way to follow, in this case taking into consideration the properties of the bilingual input.

Putting aside the possible reasons of the absence of discrimination in bilinguals, the results of Chapter 3 provided for the first time evidence of a difference in monolingual and bilingual non-native discrimination in the first year of life.

In the Chapter 4, we investigated the backward semantic inhibition in bilingual toddlers but our results were inconclusive.

Overall, the lack of replication with our stimuli and the partial replication with the same stimuli as Chow et al. (2019) suggests that the strong semantic relationship between the prime and the target had a critical role in the appearance of backward semantic inhibition. This is in line with the results reported by Arias-Trejo and Plunkett (2013) who did not find semantic priming effects in 21 month-olds though these effects were found at the same age in a previous study (Arias-Trejo and Plunkett, 2009). The authors proposed that the different semantic relationship between their prime and target stimuli in their two studies (both associatively *and* taxonomically related in the first study but only taxonomically *or* only associatively related in the second) may have influenced the results. Our current results seem to point in a similar direction of the nature of the semantic relationship between the prime and target influencing the observation of inhibitory effects.

Another possibility for the lack of replication with our stimuli could also be due to a methodological problem with one of the intervening stimulus (bath soap) that was not recognized by several of our participants preventing the switch between semantic categories and by consequence the observation of backward semantic inhibition. This result highlights again the importance of the choice of the stimuli.

Even if we partially replicated the pattern of results when testing our participants with Chow et al's stimuli, the results have to be interpreted cautiously as the sample size was very small. We could only analyze the results of 25 monolinguals (12 in the large vocabulary size group) and 15 bilinguals (7 in the large vocabulary size) while Chow et al. (2019) reported the results of 70 participants (35 in each vocabulary size group). More participants are needed before confirming that the results we found are robust. The absence of control of the stimuli that were merely translated from English to Catalan also prevents us to draw firm conclusions on these results.

A question that remains open is the nature of the information allowing for backward semantic inhibition (words or concepts). Indeed, because of the small sample size we did not perform the split according to the vocabulary score in the target language as planned. Such analyses would require a much larger sample size because of the strong correlation between the conceptual vocabulary and the dominant language.

It is important to test new participants with new stimuli to better assess the backward semantic inhibition in toddlers. Because we wanted to minimize the use of cognates, one possibility could be to test bilingual participants learning distant languages such as Spanish and Basque or English and Mandarin. As distant languages share fewer cognates than close languages as Spanish and Catalan, the choice of the stimuli would be facilitated and the semantic relationship would be better controlled.

5.3 Conclusion

In the present dissertation we provided evidence of an impact of bilingualism in adults concerning the use of word-level information when learning a non-native contrast. We also found that, contrary to the current opinion in second-language teaching studies that exposure to minimal pairs facilitates discrimination, exposure to minimal pairs hinders discrimination. This result offers a possibility of developing new L2 sounds teaching techniques. Our results with the infant data provided evidence of differences in monolingual and bilingual non-native discrimination during the first year of life suggesting an impact of early bilingual exposure on non-native discrimination abilities but not on the use of word-level information. Finally, we could not conclude on the emergence of inhibitory effects in bilingual lexicon and if this effect was modulated by the vocabulary size. Further investigation is needed to better assess such effects.

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ANNEXES

Annex 1

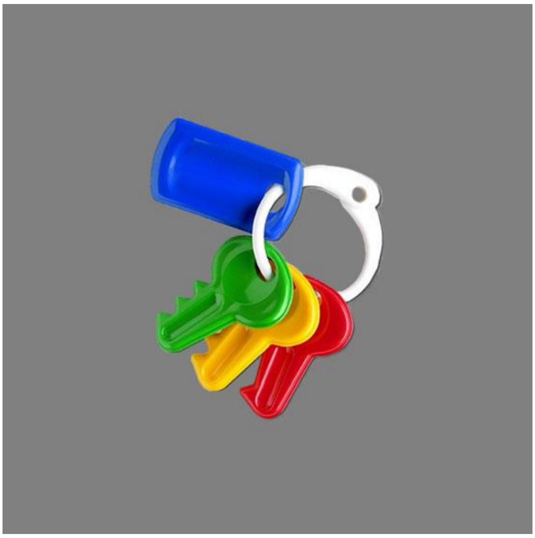
Pictures used for the Experiment 1a and 1b.

<u>Prime picture</u>: *Samarreta* (t-shirt)

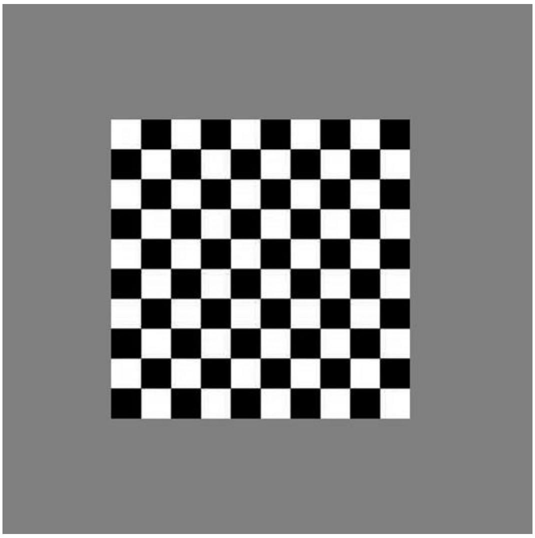
Prime picture: *Cullera* (spoon, also exist oriented to the right)

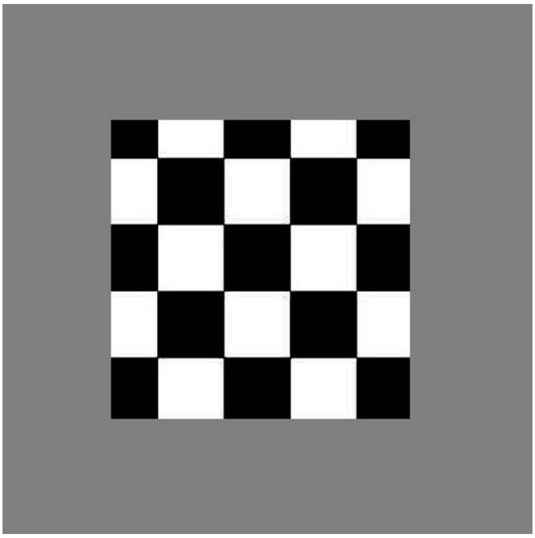
Intervening stimulus picture (word condition): S*abó* (bath soap)

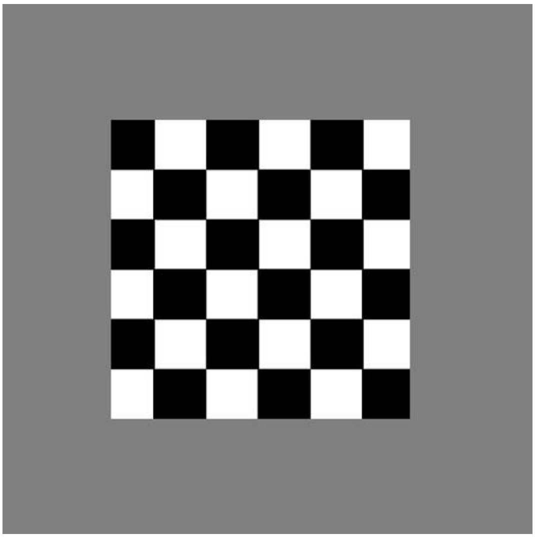
<u>Intervening stimulus picture (word condition)</u>: *Claus* (baby keys, also exist oriented to the right)

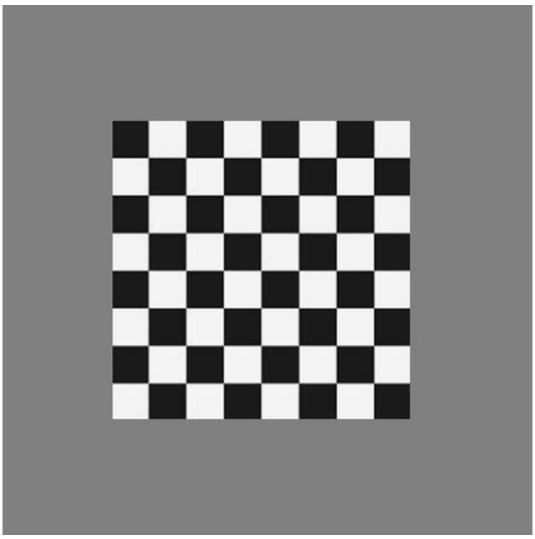


<u>Intervening stimulus picture (tone condition)</u>: square checkerboard

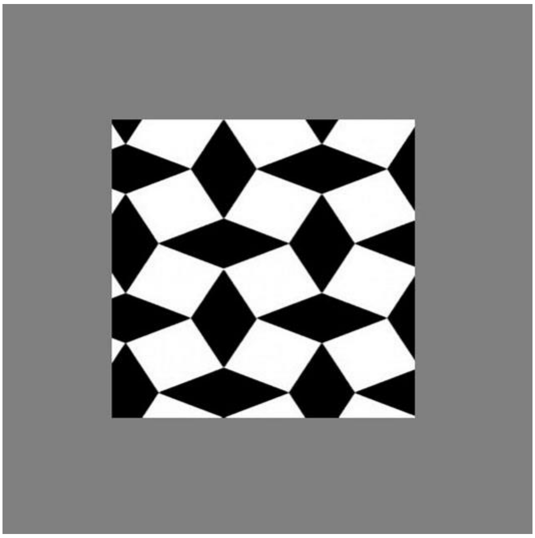


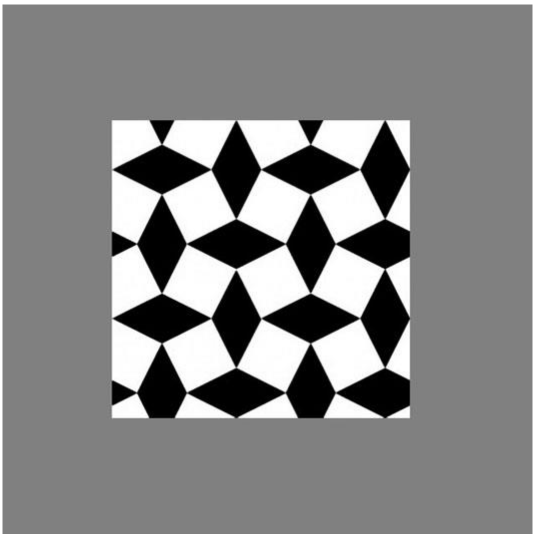


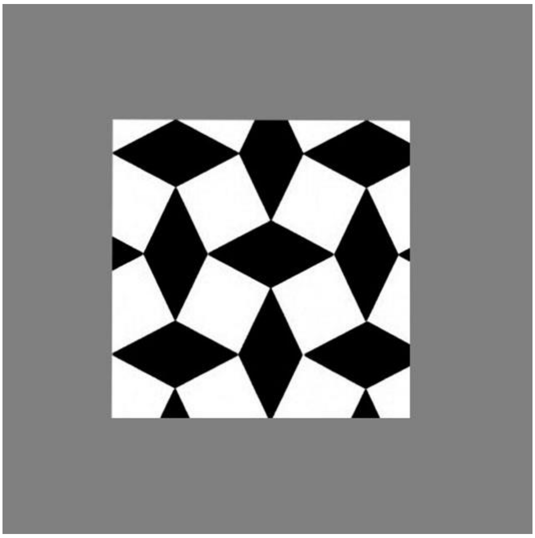


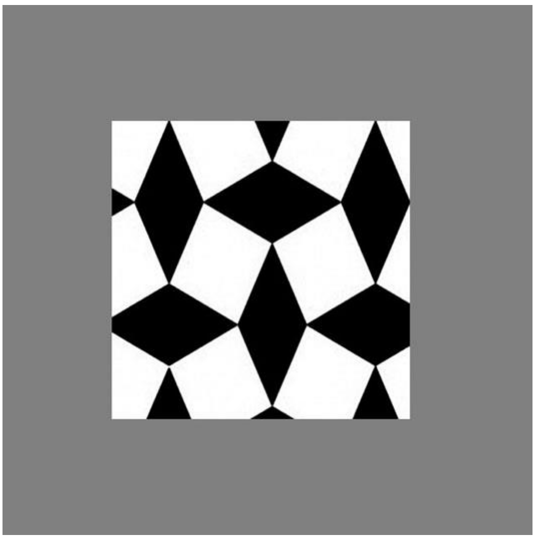


<u>Intervening stimulus picture (tone condition):</u> diamond checkerboard



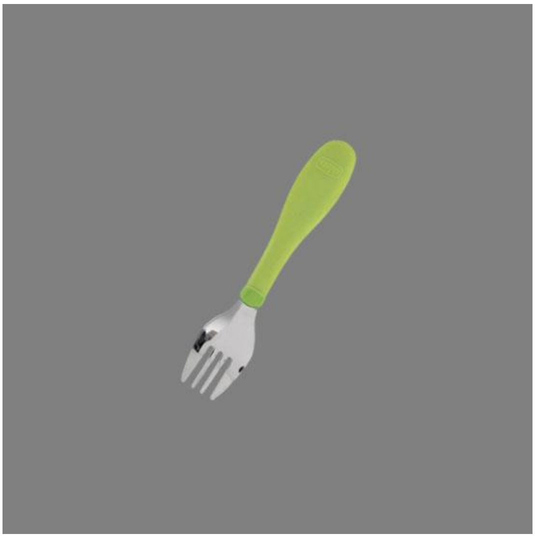






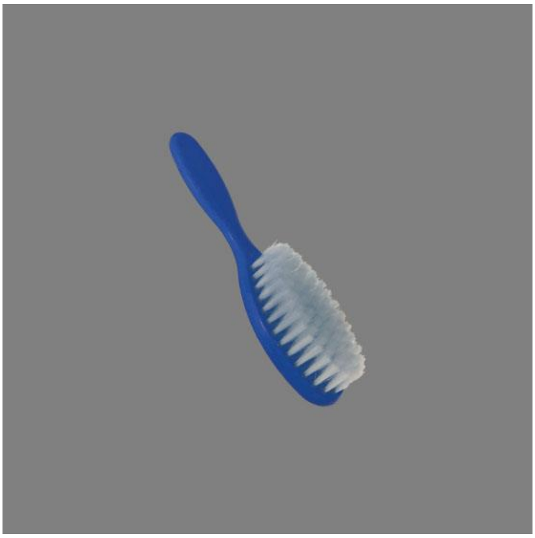
Target picture: *Mitjons* (socks, also exist oriented to the left)

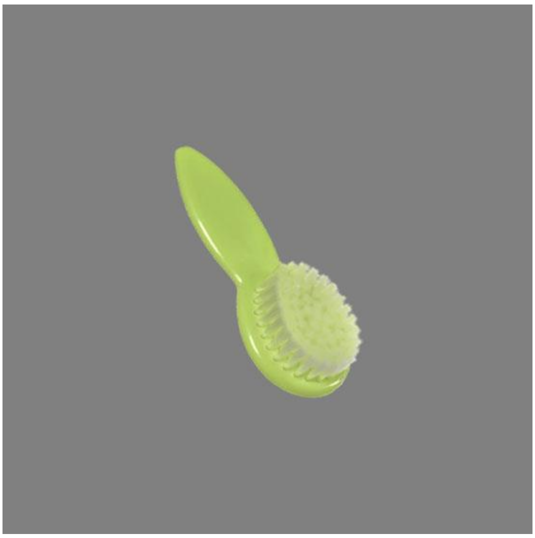
<u>Target picture</u>: *Forquilla* (fork, also exist oriented to the right)

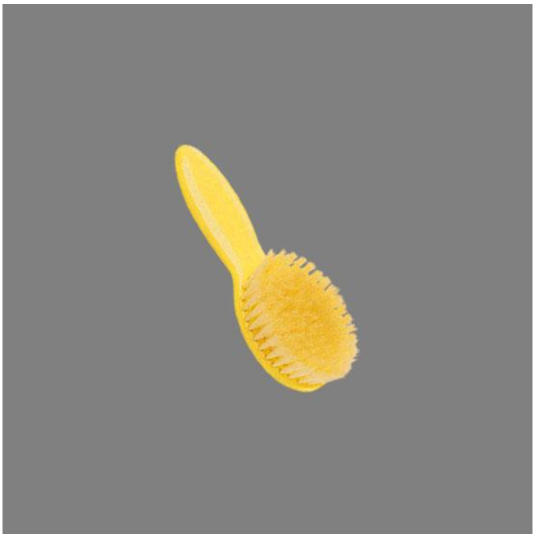


<u>Distractor picture</u>: *Taula* (table, also exist oriented to the right)

<u>Distractor picture</u>: *Raspall* (baby brush, also exist oriented to the left)







Annex 2

Pictures used for the Experiment 2a and 2b (same pictures as in Chow et al. (2019)).

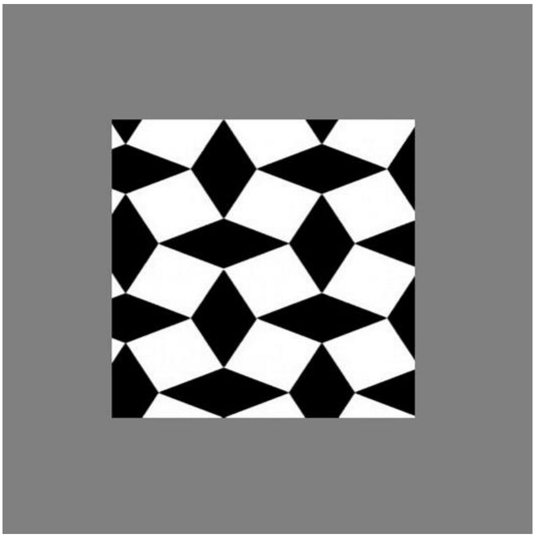
Prime picture: *Silla* (chair, also exist oriented to the left)

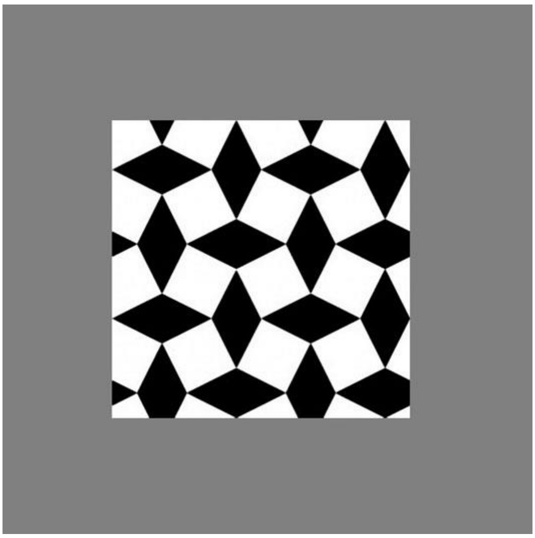
<u>Prime picture</u>: *Jaqueta* (jacket, replacing coat in the original study)

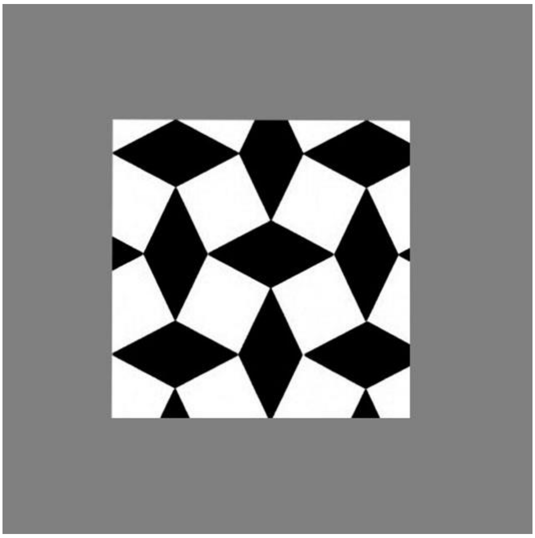
<u>Intervening stimulus picture (word condition)</u>: *Cotxe* (car, also exist oriented to the right)

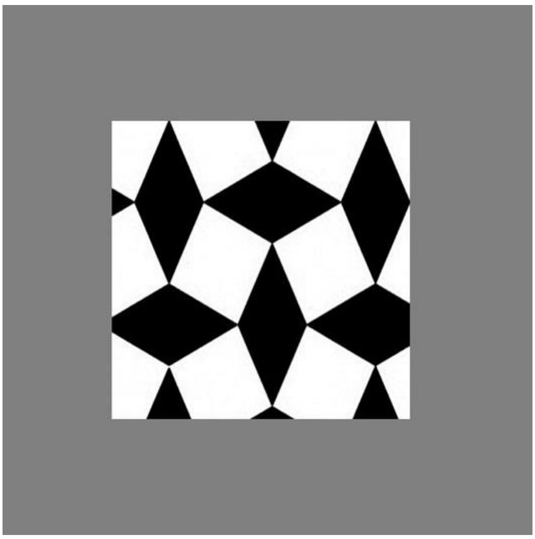
<u>Intervening stimulus picture (word condition)</u>: *Gallina* (chicken, also exist oriented to the left)

Intervening stimulus picture (tone condition): diamond checkerboard

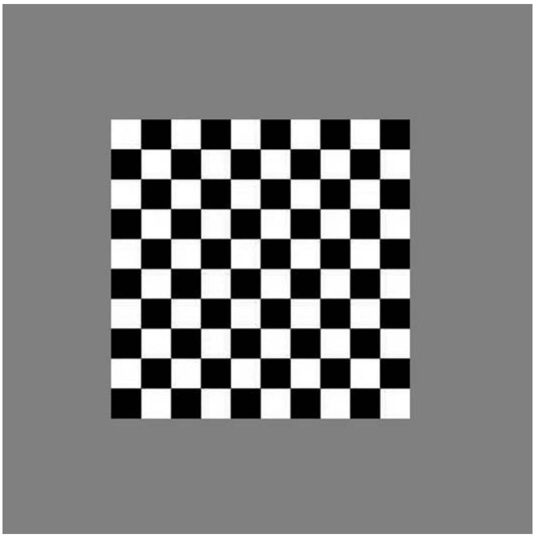


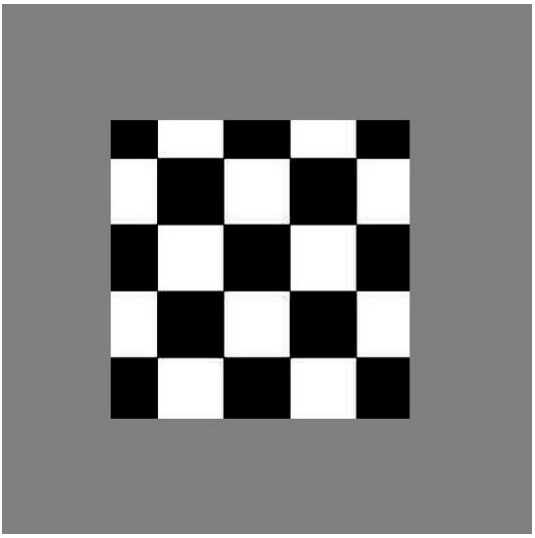


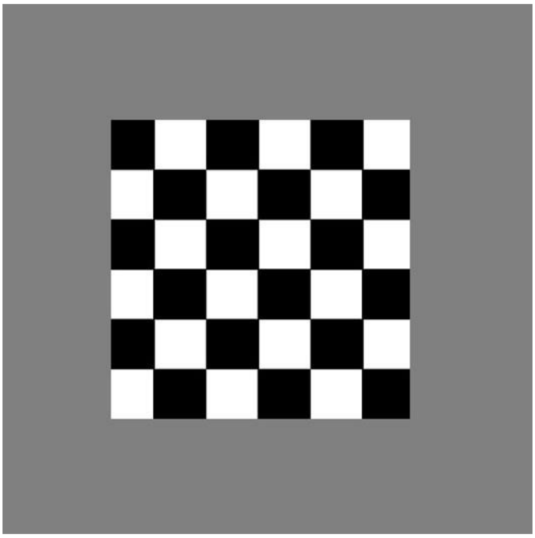


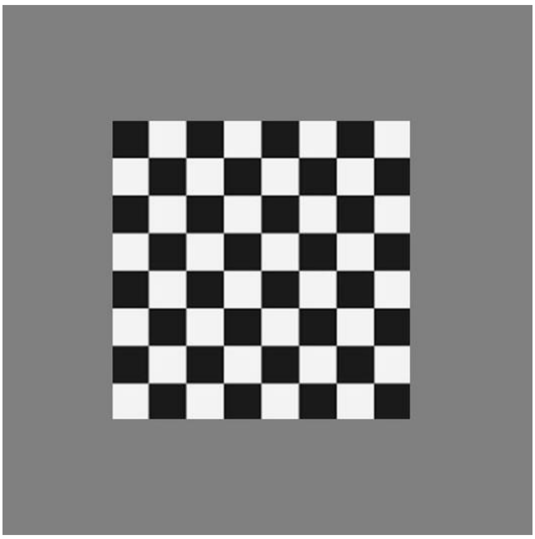


<u>Intervening stimulus picture (tone condition)</u>: square checkerboard







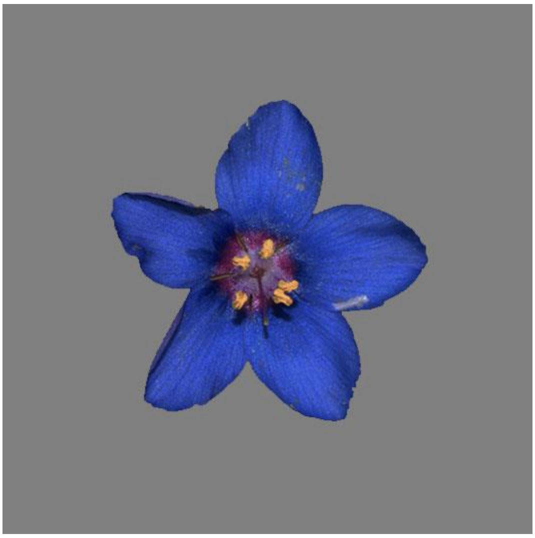


Target picture: Taula (Table, also exist oriented to the right)

Target picture: *Gorro* (hat)

Distracter picture: *Globos* (balloons)

<u>Distracter picture</u>: *Flor* (flower)



Annex 3

Table 4.17 Detail of the vocabulary scores obtained by the monolingual participants with small vocabulary size in Experiment 1a for the language questionnaire and the experimental words in Catalan and in Spanish. (NA: Not Asked, because the participant was not exposed to Spanish).

Vocabulary group	Age	ID	Percentage of Language Exposure (Cat/Spa)	Total score Catalan (/99)	Total score Spanish (/99)	Experimental words Catalan (/8)	Experimental words Spanish (/8)
small	18	26211	95/5	33	15	3	0
small	18	26382	90/10	61	35	4	3
small	18	26516	95/5	61	0	5	0
small	18	26630	95/5	20	9	3	0
small	18	26980	90/10	24	17	2	2
small	18	27125	95/5	44	43	1	4
small	18	27388	100	61	NA	8	NA
small	18	27908	98/2	55	35	5	0
small	18	27916	90/10	53	32	4	0
small	18	28241	100	19	NA	0	NA
small	18	28404	95/5	54	0	8	0
small	18	28407	100	57	NA	8	NA
small	18	28457	90/10	44	25	3	1
small	18	28482	100	53	NA	3	NA
small	18	28505	95/5	62	18	7	0
small	18	28771	100	42	NA	2	NA
small	18	28917	95/5	62	37	6	0
small	18	29622	100	62	NA	7	NA
small	18	30081	95/5	52	5	7	5
small	18	33092	100	36	NA	2	NA
small	18	33916	95/5	62	31	6	1
small	18	34102	95/5	56	56	4	1
small	18	34120	90/10	25	missing	2	missing
small	18	34272	100	39	NA	1	NA
small	18	34707	100	53	NA	2	NA
small	18	34731	90/10	44	42	4	2
small	18	34976	100	37	NA	5	NA

small	18	35009	95/5	52	missing	6	missing
small	18	35234	100	54	NA	7	NA
small	18	35563	100	48	NA	6	NA
small	24	39167	100	59	NA	6	NA
small	24	39358	100	52	NA	5	NA
small	18	44021	95/5	57	50	7	7

Table 4.18 Detail of the vocabulary scores obtained by the monolingual participants with large vocabulary size in Experiment 1a for the language questionnaire and the experimental words in Catalan and in Spanish. (NA: Not Asked; guarde: the participant was exposed to Spanish in the kindergarten mainly with the other infants).

Vocabulary group	Age	ID	Percentage of Language Exposure (Cat/Spa)	Total score Catalan (/99)	Total score Spanish (/99)	Experimental words Catalan (/8)	Experimental words Spanish (/8)
large	18	25940	95/5	81	29	8	0
large	18	26331	100	69	NA	7	NA
large	18	27851	100	66	NA	6	NA
large	18	28277	90/10	63	52	8	1
large	18	29251	95/5	66	15	7	0
large	18	29274	100	79	NA	6	NA
large	18	30007	100	66	NA	7	NA
large	18	30008	100	68	NA	6	NA
large	18	32961	100	75	NA	5	NA
large	18	32985	90/10	71	70	8	8
large	18	33038	95/5	84	43	8	0
large	18	33863	100	68	NA	7	NA
large	18	35464	100	89	NA	8	NA
large	24	37796	92/8	71	0	7	0
large	24	40254	98/2	73	31	8	0
large	24	41903	97/3	95	87	8	7
large	24	42285	100	90	NA	8	NA
large	24	42905	100	85	NA	8	NA
large	18	45560	100	65	NA	6	NA
large	24	46892	97/3	95	40	8	0
large	24	47155	93/7	89	57	8	2
large	24	47279	98/2	73	guarde	6	guarde
large	24	47398	99/1	80	16	8	0
large	24	47607	100	95	NA	8	NA
large	24	47620	98/2	94	7	8	0
large	24	47999	98/2	88	15	7	1
large	24	48000	100	90	NA	8	NA
large	24	48661	96/4	77	39	7	1
large	24	50904	100	84	NA	7	NA

large	24	51274	100	98	NA	8	NA
large	24	51689	99/1	86	6	8	0
large	24	54119	100	99	NA	8	NA
large	18	29323	100	62	NA	7	NA

Table 4.19 Detail of the vocabulary scores obtained by the bilingual participants in Experiment 1b for the language questionnaire and the experimental words in Catalan and in Spanish with their corresponding concept scores.

Vocabulary group	Age	ID	Percentage of Language Exposure (Cat/Spa)	Total score Catalan (/99)	Total score Spanish (/99)	Concept score (/99)	Expe. words Catalan (/8)	Expe. words Spanish (/8)	Expe. words Concept (/8)
small	18	25733	60/40	42	37	49	5	4	6
small	18	26428	70/30	52	53	59	5	8	8
small	18	26493	60/40	68	68	68	7	7	7
small	18	26873	45/55	52	47	55	3	1	3
small	18	28197	65/35	51	22	53	6	0	6
small	18	29283	70/30	61	45	63	7	3	7
small	18	29685	50/50	54	59	61	7	8	8
small	18	29839	30/70	28	54	59	2	7	7
small	18	30005	65/35	28	25	35	1	3	3
small	18	30282	75/25	20	17	20	1	0	1
small	18	32948	70/30	59	48	59	6	6	6
small	18	32974	60/40	75	73	80	5	0	5
small	18	33013	65/35	52	40	60	3	5	6
small	18	33076	74/26	56	38	59	5	2	6
small	18	33139	65/35	48	46	54	4	4	6
small	24	35570	52/48	37	27	44	4	2	4
small	18	39356	75/25	77	47	78	8	1	8
small	24	39537	75/25	38	21	38	6	1	6
small	24	46881	73/27	52	46	60	5	4	5
small	24	52360	65/35	71	46	73	8	4	8
large	18	28862	45/55	70	84	85	3	7	7
large	18	33099	60/40	80	41	82	8	0	8
large	18	33141	75/25	82	59	82	8	6	8
large	24	42568	63/37	86	86	86	7	7	7
large	24	45585	71/29	71	77	84	8	8	8
large	24	46875	70/30	93	93	93	8	8	8
large	24	47205	65/35	85	83	87	8	8	8
large	24	47264	57/43	83	71	87	8	8	8
large	24	47276	34/66	54	95	95	3	8	8
large	24	47593	55/45	76	78	83	8	8	8
large	24	47614	57/43	77	75	82	7	7	7

large	24	47685	67/33	97	57	97	7	6	8
large	24	48660	70/30	88	87	93	8	8	8
large	24	48723	52/48	96	63	97	8	7	8
large	24	50790	65/35	72	41	84	6	2	6
large	24	50818	60/40	88	87	91	8	8	8
large	24	51822	64/36	98	99	99	8	8	8
large	18	33743	70/30	79	66	80	8	4	8
large	24	46998	34/66	74	78	80	7	8	8

Table 4.20 Detail of the vocabulary scores obtained by the monolingual participants in Experiment 2a for the language questionnaire and the experimental words in Catalan and in Spanish (NA: Not Asked, because the participant was not exposed to Spanish).

Vocabulary group	Age	ID	Percentage of Language Exposure (Cat/Spa)	Total score Catalan (/99)	Total score Spanish (/99)	Experimental words Catalan (/8)	Experimental words Spanish (/8)
small	18	34272	100	39	NA	1	NA
small	18	33916	95/5	62	31	6	1
small	18	34976	100	37	NA	5	NA
small	18	35563	100	48	NA	6	NA
small	18	40135	95/5	67	9	7	0
small	18	37938	100	53	NA	5	NA
small	18	40482	90/10	74	79	6	8
small	18	44859	100	80	NA	8	NA
small	18	42039	100	50	NA	3	NA
small	18	43532	100	65	NA	5	NA
small	24	42046	100	58	NA	6	NA
small	24	39167	100	59	NA	7	NA
small	24	48661	96/4	77	39	8	1
large	24	43175	95/5	85	72	8	7
large	24	40377	97/3	90	69	8	3
large	24	54754	100	87	NA	8	NA
large	24	41903	97/3	95	87	8	7
large	24	54119	100	99	NA	8	NA
large	24	47607	100	95	NA	8	NA
large	24	48000	100	90	NA	8	NA
large	24	47620	98/2	94	7	8	0
large	24	50012	98/2	84	92	8	8
large	24	50904	100	84	NA	7	NA
large	18	35464	100	89	NA	8	NA
large	18	39899	100	81	NA	8	NA

Table 4.21 Detail of the vocabulary scores obtained by the bilingual participants in Experiment 2b for the language questionnaire and the experimental words in Catalan and in Spanish with their corresponding concept scores.

Vocabulary group	**Age**	**ID**	**Percentage of Language Exposure (Cat/Spa)**	**Total score Catalan (/99)**	**Total score Spanish (/99)**	**Concept score (/99)**	**Expe. words Catalan (/8)**	**Expe. words Spanish (/8)**	**Expe. words Concept (/8)**
small	24	39537	75/25	38	21	38	4	2	4
small	24	45585	71/29	71	77	84	5	8	8
small	24	46881	73/27	52	46	60	6	3	6
small	24	47593	55/45	76	78	83	7	8	8
small	24	47614	57/43	77	75	82	6	6	7
small	24	46998	34/66	74	78	80	7	8	8
small	24	50790	65/35	72	41	84	6	2	8
small	24	52360	65/35	71	46	73	8	1	8
large	24	36915	53/47	81	90	92	8	8	8
large	24	46875	70/30	93	93	93	8	8	8
large	24	48723	52/48	96	63	93	8	5	8
large	24	50849	70/30	97	97	97	8	8	8
large	24	51684	44/56	84	42	85	8	5	8
large	24	51035	68/32	93	90	93	8	8	8
large	24	51280	51/49	78	99	99	8	8	8