Language acquisition in bilingual infants. Early language discrimination in the auditory and visual domains

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A mi familia.

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ABSTRACT

Learning language is a cornerstone in the cognitive development during the first year of life. A fundamental difference between infants growing up in monolingual versus bilingual environments is the necessity of the latter to discriminate between two language systems since very early in life. To be able to learn two different languages, bilingual infants will have to perceive the regularities of each of their two languages while keeping them separated. In this thesis we explore the differences between monolingual and bilingual infants in their early language discrimination abilities as well as the strategies that arise for each group as a consequence of their adaptation to their different linguistic environments.

In chapter two, we examine the capacities of monolingual and bilingual 4-month-old infants to discriminate between their native/dominant language from foreign ones in the auditory domain. Our results show that, in this context, bilingual and monolingual infants present different brain signals, both in the temporal and the frequency domain, when listening to their native language. The results pinpoint that discriminating the native language represents a higher cognitive cost for bilingual than for monolingual infants when only auditory information is available.

In chapter three we explore the abilities of monolingual and bilingual 8-month-old infants to discriminate between languages in the visual domain. Here we show to infants never exposed to sign

languages videos of two different sign languages and we measure their discriminatory abilities using a habituation paradigm. The results show that at this age only bilingual infants can discriminate between the two sign languages. The results of a second control study points in the direction that bilinguals exploit the information coming from the face of the signer to make the distinction.

Altogether, the studies presented in this thesis investigate a fundamental ability to learn language - specially in the case of bilingual environments - which is discriminating between different languages. Compared to a monolingual environment, being exposed to a bilingual environment is characterized by receiving more information (2 languages) but with less exposure to each of the languages (on average half of the time to each of them). We argue that the developmental brain is as prepared to learn one language from birth, as it is to learn two. However, to do so, monolingual and bilingual infants will develop particular strategies that will allow them to select the relevant information from the auditory and visual domains.

RESUMEN

La adquisición del lenguaje es una pieza fundamental en el desarrollo cognitivo durante el primer año de vida. Una diferencia fundamental entre los bebés que crecen en ambientes monolingües y bilingües es que estos últimos necesitan discriminar entre dos sistemas lingüísticos desde muy temprano en la vida. Para poder aprender dos idiomas, los bebés bilingües tienen que percibir las regularidades de cada uno de sus idiomas y a la vez mantenerlos separados. En esta tesis exploramos las diferencias entre bebés monolingües y bilingües tanto en sus capacidades de discriminación tempranas, como en las estrategias que desarrolla cada grupo como consecuencia de la adaptación a su entorno lingüístico.

En el segundo capítulo, examinamos la capacidad de los bebés bilingües y monolingües a los 4 meses de edad para discriminar entre la lengua nativa/dominante de otra extranjera en el dominio auditivo. Nuestros resultados muestran que, en este contexto, los bebés monolingües y bilingües presentan diferentes señales auditivas cuando escuchan su lengua nativa. Los resultados señalan que discriminar la lengua nativa representa un coste cognitivo mayor para los bebés bilingües que para los monolingües cuando sólo sólo disponen de información auditiva.

En el capítulo 3, exploramos las habilidades de los bebés monolingües y bilingües a los 8 meses de edad para discriminar lenguas en el dominio visual. Aquí, mostramos a bebés que nunca han sido expuestos a lengua de signos, videos de dos lenguas de signos diferentes y medimos sus habilidades discriminatorias usando un paradigma de habituación. Los resultados muestran que a esta edad sólo los bebés bilingües son capaces de hacer la distinción y apuntan que para ello aprovechan la información proveniente de la cara de la signante.

En resumen, los estudios presentados en esta tesis investigan una habilidad fundamental para aprender lenguaje - especialmente en el caso de entornos bilingües - que es discriminar entre diferentes lenguas. En comparación con un entorno monolingüe, estar expuesto/a a un entorno bilingüe se caracteriza por recibir más información (2 idiomas) pero con menos exposición a cada una de ellas (de media, la mitad de tiempo a cada una de ellas). Nosotras argumentamos que el cerebro del bebé está tan preparado para aprender un idioma desde el nacimiento, como lo está para aprender dos. Sin embargo, para poder hacerlo, los bebés monolingües y bilingües desarrollan diferentes estrategias que les permiten seleccionar la información relevante del dominio auditivo y visual.

PREFACE

The capacity of infants to learn languages since birth –or even earlier- is a major accomplishment that has captured the attention of researchers for decades. Today the majority of the world's population is exposed to two languages since birth (Werker & Byers-Heinlein, 2008). Two confronting views have been encountered when framing the bilingual language acquisition. Petitto & Kovelman (2003) elegantly named the "bilingual paradox" to the fact that while ones support that infants master learning one or two languages effortlessly, others are worried that learning two languages at the same time will produce delays and confusion.

Empirical evidence supports the first view, as bilingual infants arrive to their language developmental milestones at the same age as their monolingual peers (Costa & Sebastián-Gallés, 2014; Oller, Eilers, Urbano, & Cobo-Lewis, 1997; Pearson & Fernández, 1994; Petitto et al., 2001; Sebastian-Galles, 2010). Also the vocabulary sizes of bilinguals and monolinguals are similar (when both of the languages are taken into account for bilinguals): both bilingual and monolingual infants start producing their first word at the same age (at around 1 year), and 6 months later both groups are able to produce around 50 words (Pearson, Fernández, & Oller, 1993; Pearson & Fernández, 1994). Together all of the evidence converges to show that the infant's brain is as prepared to learn a single language as it is to learn two languages (Werker & Byers-Heinlein, 2008).

However, what we argue is that bilingual language acquisition is not only characterized by the acquisition of more linguistic information or, as F. Grosjean said in reference of the bilingual adult *"A bilingual is not two monolinguals in one person"* (Grosjean, 1989, p.2). Learning two different languages means learning two phonological, lexical and grammar systems that overlap to some extend and crucially, learning them since birth will include the necessity of continuously discriminate between the two languages in use. Here we argue that, to be able to attain the same developmental milestones, bilingual infants have to perform *specific adaptations* to their linguistic environment and that language discrimination is an important stepping-stone in the language learning process.

Table of contents

CHAPTER 1. INTRODUCTION

The first sections of this thesis report a brief review of the initial steps in language acquisition with an special emphasis in the first year of life covering the establishing of the phoneme repertoire(s) and the learning of rules of language. These sections focus on the studies comparing monolingual and bilingual infants and help framing the specific adaptations that bilinguals perform to attain their linguistic milestones. Following, detailed empirical results on language discrimination in monolingual and bilingual populations will be described.

1.1 Auditory processing of speech

1.1.1. Phonetic development

Infants begin their life being able to discriminate between most of the possible phonetic contrasts. During the first year of life, exposure to a native language allows infants to group the sounds in the necessary categories to build their native phonetic repertoire. Concretely, during second semester of life the discriminative capacity for phonemes decreases for non-native phonetic contrasts (Werker & Tees, 1984).

The first study exploring this effect was conducted by Werker, Gilbert, Humphrey & Tees (1981). The experimenters tested the ability of adults and 6-8 month old infants to discriminate between two similar speech sounds that are used to contrast meaning in Hindi but not in English. They found that while English learning infants and adult Hindi speakers could discriminate between both phonemes, adult English speakers had difficulties in noticing the difference. Werker & Tees, (1984) tested the ability of monolingual infants to discriminate between these phonetic contrasts at different ages. They found that the pattern of discrimination changed during the second semester of life. At 6-8 months of age infants were able to discriminate between the sounds. By 10-12 months of age, monolingual English infants had lost this ability while Salish and Hindi monolingual infants kept it.

This process known as *perceptual narrowing* shows that, although infants come to life with broad sensitivities towards possible phonetic contrasts, during the second semester of life, they experience a decline in sensitivity towards contrasts that do not appear in their linguistic environment. This process begins slightly earlier for vowels, at around 6-8 months of age (Bosch & Sebastián-Gallés, 2003; Cheour et al., 1998; Polka & Werker, 1994) and a bit later for consonants at around 8-10 months of age (Werker & Tees, 1984). This pattern has been described when measured in behavioral paradigms as well as with EEG (both in ERPs and time-frequency domain) or MEG (Bosseler et al., 2013; Garcia-Sierra et al., 2011; Ortiz-Mantilla, Hämäläinen, Musacchia, & Benasich, 2013; Peña, Werker, & Dehaene-Lambertz, 2012).

The bilingual learner is exposed to two phonemic repertoires, which overlap in a higher or smaller proportion depending on the pair of languages to be learned. Still, studies on phonemic discrimination show a similar pattern of discrimination for bilingual and monolingual infants both for consonants (Burns, Yoshida, Hill, & Werker, 2007; Sundara, Polka, & Molnar, 2008) and vowels (Albareda-Castellot, Pons, & Sebastián-Gallés, 2011). In the case of Catalan-Spanish bilingual infants the first studies on language discrimination using a familiarity procedure showed a u-shaped pattern by which infants would show discrimination of the /e-ɛ/ contrast at 4 and 12 months of age but not at 8 (Bosch & Sebastián-Gallés, 2003; Sebastián-Gallés & Bosch, 2009). However, later studies using the same phonemic contrast but this time using an anticipatory-eye-movement showed that at 8 months Catalan-Spanish bilinguals were able to discriminate as well as Catalan monolinguals (Albareda-Castellot et al., 2011). Probably, the habituation procedure used in the previous studies was hiding the infants' discriminatory abilities (Sebastian-Galles, 2010) .

The work on phoneme discrimination shows that although infants come to life with initial sensitivities to discriminate between most of the phonemes of the world, the exposure to a native language attunes them towards the characteristics of their native language.

1.1.2. Learning the rules of language

To learn a language infants need to extract the regularities that govern it. Bilingual infants will have to detect and learn the regularities that define each of their native languages, as phonotactics, rule learning and word order.

Phonotactics

Phonotactics refer to which combination of phonemes can or cannot form a word in a certain language. Around 9 months of age, and not earlier, monolingual infants start extracting the phonotactic information of the words (Friederici & Wessels, 1993) and prefer listening to the words that follow the phonotactic rules of their native language over the ones that do not (Jusczyk & Luce, 1994).

Infants growing up in multilingual environments might encounter different phonotactic rules for each of their languages. Sebastián-Gallés & Bosch (2002) presented bilingual and monolingual Catalan-Spanish infants with lists non-words, some of them being possible and other non-possible in Catalan and all of them impossible in Spanish. For the monolingual groups, only Catalan native but not Spanish native infants showed a preference for the phonotactically possible Catalan words. The results of the bilingual infants depended of the dominant language. Catalan dominant bilingual infants showed a preference for the possible words. However, Spanish-dominant bilingual infants did not show a strong preference for the possible words. Their results point in the direction that the mechanisms for phonotactic acquisition might require a minimum exposure to a language a reason why bilinguals might be slower in findinf the phnotactic rules in their non-dominant language.

Rule learning

Rule learning studies explore how infants deal with the extraction of linguistic regularities by presenting infants with simplified grammars composed by syllables that follow a certain rule. For instance, the sequence of syllables *lo-lo-vu* could instantiate an ABB rule and *lo-vu-lo* an ABA rule.

The research of Marcus, Vijayan, Bandi Rao, & Vishton (1999) revealed that at 7 months of age, monolingual infants are able to detect a linguistic rule, for instance infants can extract ABA or ABB rules, and generalize them. Kovács & Mehler (2009) explored the flexibility of bilingual infants to learn multiple structural regularities at 12 months of age. The experimenters presented the infants with two simultaneous rules, one being AAB and one being ABA. In an anticipatory-eye-movement procedure, they tested whether the infants associated the presence of each of the rules with a reward in each of the sides of the screen. They found that bilinguals were able to associate each of the rules with a reward in each side of the screen while monolinguals could only do it for the AAB rule. They concluded that bilinguals seemed to be more flexible to learn multiple structural regularities as compared to monolinguals.

Word order

One of the fundamental syntactic properties is the order in which constituents appear within a sentence (the so-called language word order). For instance English, a VO language in which the verb appears before the object in a sentence and Japanese, an OV language where the order of appearance is the reverse. Infants learning two languages with different word objects will have to detect the two different rules.

Acording to Nespor et al., (2008) correlates exist between prosody and word order across languages. Following Gervain (2008), Gervain and Werker (2013) tested whether exposure to specific syntactic rules shaped the way that 7-month-old monolingual and bilingual infants learned new rules. They presented to monolingual and bilingual infants (who were learning an OV and a VO language) a speech stream with a prosody that could cue infants to parse the stream either as an OV language or as a VO language. The researchers found that, monolinguals could only parse the stream when it corresponded to the prosody of their native language, but bilinguals could do it for both (OV and VO) prosodies.

Exposure to a bilingual input makes bilingual infants more flexible to detect and generalize two rules taking place in parallel. From an early age, bilinguals will exploit the cues of the speech stream that mark the regularities for each of the languages they have to learn.

1.2. Audiovisual language processing

The vast majority of research on language acquisition has been done in the auditory modality. However, research using audiovisual stimuli has found that monolingual and bilingual infants exploit differently the articulatory information present in the face that complements the auditory one?

Studies presenting a talking face to infants, have found a U shape trajectory in their scanning patterns during the first year of life. Lewkowicz & Hansen-Tift (2012) found that, at 4 months of age monolingual infants look longer to the eye area, but at 8 months of age they switch their preference looking towards the mouth area. At 12 months of age, monolingual infants keep looking longer to the mouth region when presented with a foreign language but if the face presented is talking in their native language infants focus on the eyes area. Looking longer to the mouth at 8 months allow infants to pay attention to redundant audiovisual information that is necessary to establish the native repertoire at an age when they start babbling. Once they have acquired some expertise in their native language the second shift towards the eye region takes place at 12 months of age and that would allow infants to focus on social cues. However at this age they would still need to focus in the mouth area when exposed to a foreign language, as those languages would be more difficult to process after phonological narrowing (Lewkowicz & Hansen-Tift, 2012).

Pons, Bosch, & Lewkowicz (2015), extended the original study comparing monolingual and bilingual infants at 4, 8 ant 12 months of age with a parallel procedure and materials. For the monolingual group the previous looking pattern was replicated but the researchers found that bilinguals looked to the mouth for a longer period than monolinguals. Bilinguals looked equally to the mouth and eyes at 4 months, but at 8 and 12 looked longer to the mouth region (See figure 1). This pattern was found both for the native and foreign languages. Bilinguals were paying attention to redundant audiovisual cues since earlier in life and for a longer time. The authors concluded that this strategy would allow them to identify specific features for each of their languages and to build two separated language systems.

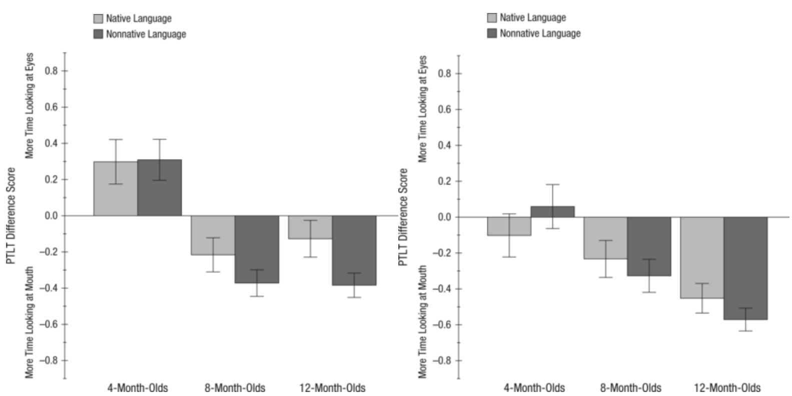

Figure 1. Reproduced from Pons et al., (2015) In the left the results of monolingual Catalan/Spanish are plotted, in the right the results of bilingual Catalan-Spanish infants are plotted.

More recently, Ayneto and Sebastián-Gallés (in press) expanded these results and found that the focus of bilinguals in the mouth region was extended to situations in which speech was not present. The researchers presented short video clips of people (both infants and adults) showing different emotional states and found that 8-month-old bilingual infants looked overall longer to the mouth region when presented with this materials that did not contain speech.

Together, the results of the studies presenting faces in an audiovisual setting show that bilinguals look longer to the mouth region and that this effect is not exclusive to the presentation of speech. This looking pattern is related to their more challenging language learning situation, as their linguistic input is more complex and, on average, with a more reduced amount of input to each of their languages than the one of the monolinguals.

The presented research in bilingual language acquisition show that bilingual infants are not confused or delayed in acquiring the linguistic milestones when compared to their monolingual peers. During the first year of life both bilingual and monolingual infants begin building their native phonemic repertoire and learn to extract the rules that govern their native/s language/s at different levels. But importantly, although they arrive to the same goals, the previous research shows that the developmental trajectory of bilinguals differs from that of monolinguals (Sebastian-Galles, 2010).

Bilingual infants create their own strategies to extract the cues that allow them to handle their linguistic environment.

1.3. Language discrimination

Some of the literature on early language acquisition in infancy (specially newborns) has focused in the language discrimination abilities. Discriminating between native and foreign languages is fundamental for bilingual infants, who, since early in life, need to learn the characteristics of their two languages while keeping them differentiated.

Among the different proposals that have been put forward to explain the language discrimination abilities, maybe the one that has received most empirical support is the sensibility towards rhythmicity (Mehler, J., Dupoux, E., Nazzi, T., & Dehaene-Lambertz, 1996). Based in their fundamental timing unit, languages have traditionally been classified into three rhythmic classes named Syllabled-timed (e.g. Catalan) Stress-timed (e.g. German) and Mora- Timed (e.g. Japanese) (Abercrombie, 1967). This first classification was based in isochrony, a syllable-timed language would have isochronous syllables and a stress-timed language would have isochronous stress intervals. Ramus, Nespor, & Mehler, (1999) elaborated this theoretical proposed and suggested that languages more approximately form a continuum based on the relative distributions different dimensions as of Vocalic intervals (V%), Consonantal (C%) and the variability of Consonantal intervals (ΔC) within sentence. They suggest that rhythm would correlate with the average proportion of Vocalic intervals and the average standard deviations of consonantal intervals (See figure 2).

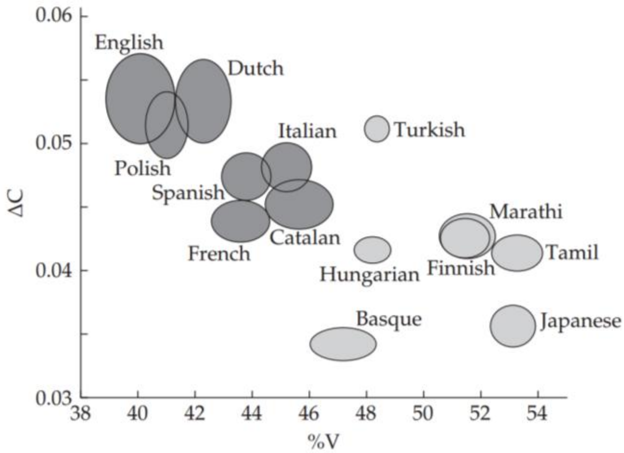

Figure 2. Reproduced from Nespor, Shukla, & Mehler, (2011). Location of stress and syllable timed languages in the ΔC (the standard deviation of the consonant intervals) %V (the amount of time per utterance spent in vowels) continuum.

Language discrimination in the first six months of life shows a developmental pattern that evolves from the ability to discriminate between languages of different rhythmic classes (such as English and Tagalog) right after birth, to the ability to discriminate languages of the same rhythmic classes (such as English and Dutch) around 5 months of age. In the following sections we review the studies on bilingual and monolingual language discrimination abilities, focusing on the first months of life.

1.3.1. Monolingual infants

Monolingual infants are able to discriminate languages from different rhythmic classes, as English and Tagalog or Dutch and Japanese, since birth (Byers-Heinlein, Burns, & Werker, 2010; Christophe & Morton, 1998; May, Byers-Heinlein, Gervain, & Werker, 2011; Mehler et al., 1988; Moon, Cooper, & Fifer, 1993; Nazzi, Bertoncini, & Mehler, 1998; Ramus, 2002). And even before birth between the 33 – 41 week of gestation, fetuses can discriminate between language pairs as English and Mandarin (Kisilevsky et al., 2009). When compared to another language from a different rhythmic class, monolingual newborns show a preference for the familiar language (Byers-Heinlein et al., 2010; Mehler et al., 1988; Moon et al., 1993). Newborns' ability to discriminate between languages of different rythmic classes extends to languages that are unfamiliar; Nazzi et al., (1998) showed that French newborns could discriminate between low-pass-filtered sentences in English and Japanese (a transformation that keeps the rhythmical properties of languages).

As expected the early discrimination abilities also show some limitations. Monolingual newborns fail discriminating language pairs from different rhythmic classes when they are played backwards (Nazzi et al 1988). Monolingual newborns fail discriminating languages of the same rythmic class as English and Dutch (Christophe & Morton, 1998; Mehler et al., 1988; Nazzi et al., 1998; Ramus, Hauser, Miller, Morris, & Mehler, 2000; Ramus, 2002).

The ability to discriminate between languages from the same rhythmic class, as Dutch and English or Catalan and Spanish develops at around 4 - 5 months of age, only if one of the languages tested is familiar (Bosch & Sebastián-Gallés, 1997, 2001; Molnar, Gervain, & Carreiras, 2014; Nazzi, Jusczyk, & Johnson, 2000; Nazzi & Ramus, 2003).

The discoveries found in newborns language abilities increased the curiosity of researchers to explore how would other mammals deal with languages discrimination, as it would shed light on the evolution of linguistic capacities. Ramus et al., (2000) explored the abilities of Cotton-Top Tamarin monkeys and human newborns in discriminating languages from different rhythmic classes (Dutch and Japanese) using a habituation paradigm. They found that both, newborn humans and monkeys were able to discriminate between the two languages either if the sentences were presented naturally produced or after a particular resynthesize of the same stimuli (which preserved the rhythmic cues of speech but eliminated phonetic and lexical information). However, both groups failed when they were presented with the same sentences played backwards, which removed the prosodic information of speech. The results with monkeys were extended to other mammals, Long-Evan rats, in a study carried by Toro, Trobalon, & Sebastián-Gallés, (2003) who found that also these animals were able to discriminate between the two languages only when played forward. The results with animals show that the ability to discriminate between languages from different rhythmic classes is not exclusive of humans and therefore might have its origins in ancient evolutionary mechanisms shared with other mammals.

1.3.2. Bilingual infants

Bilingual learners continuously need to sort the linguistic input into two different language systems. One of the main concerns on early bilingual language acquisition is that bilingual infants will be confused and will mix their two languages as a consequence of their difficulties in telling languages apart. Although to date the volume of studies on this topic is not big, the published literature points in the direction that bilinguals and monolinguals discriminate languages at the same age. In the following section empirical evidence of the early language discrimination abilities of bilingual infants is revised.

a) Auditory language discrimination

To date only a handful of studies have explored the abilities of bilingual infants to discriminate languages in the auditory domain. Byers-Heinlein et al., (2010) tested the language preference of newborns whose mother spoke either Tagalog and English or only English during pregnancy. They presented the infants with low-pass-filtered sentences of English (Stress-timed) and Tagalog (Syllable-timed), keeping the rhythmical information of each language. The authors found similar discriminatory abilities between both groups. All infants could discriminate between both languages and bilingual-to-be infants could also discriminate them from a third different language.

At 4 months of age, infants exposed to two languages since birth can also discriminate between both of their native languages as well as their monolingual peers (Bosch & Sebastián-Gallés, 2001; Molnar et al., 2014). Bosch & Sebastián-Gallés, (2001) used a familiarization-preference procedure to explore if at this age bilingual and monolingual infants discriminated between Spanish and Catalan. As expected, monolinguals were able to discriminate between both languages. The results of bilinguals showed that they could also discriminate between both of the languages and, crucially, the size of the effect was the same for both groups. Molnar et al., (2014) tested 3.5 month-old infants exposed to Basque, Spanish or the two languages with low-pass filtered sentences of both languages in a habituation paradigm. The researchers found that monolingual and bilingual infants could discriminate between both languages, although the pattern of responses differed among groups. First, Basque monolingual and Basque-Spanish bilingual infants discriminated between the two languages, but Spanish monolingual infants only succeeded when they were habituated with Basque, but not with Spanish. The autors interpreted the Spanish monolinguals' results to be influenced by native language recognition as they would have little exposure to Basque. That would not be the case for Basque monolinguals as they would have had more contact to Spanish and this language would sound more familiar to them than Basque would sound to Spanish monolinguals. Second, the bilingual group presented longer looking times during the test phase than monolinguals. This fact was taken as evidence that bilingual infants attended differently than monolinguals towards their native language.

The studies in native language discrimination can be taken as evidence that bilingual language discrimination is not hindered or delayed and such, bilingual infants are not confused about the languages spoken in their environment.

The studies reviewed before test monolingual and bilingual infants into two different situations relative to the familiarity of the languages. For bilinguals the two languages discriminated are familiar while for monolinguals one is native and the other one is foreign. To put both groups in the same situation, a foreign third language can be used as a contrast. The maternal-foreign discrimination abilities (and also the native1-native2 in one of the experiments) of infants learning Spanish and Catalan was studied by Bosch & Sebastián-Gallés (1997). Following Dehaene-Lambertz & Houston, (1998) the authors measured the orientation latencies of 4-month-old infants towards two different languages. The infants were sitting on their caregiver's lap in front of a screen (See figure 3). At both sides of the screen two loudspeakers were placed and covered by the image of a woman. Each trial began with an attention getter presented from the central screen. Once the baby fixated on the central screen, the attention getter would disappear and a sentence would be played through one of the loudspeakers either in the native or a foreign language. The orientation latency was described as the time it took the baby to disengage from the center and direct her gaze towards the loudspeaker.

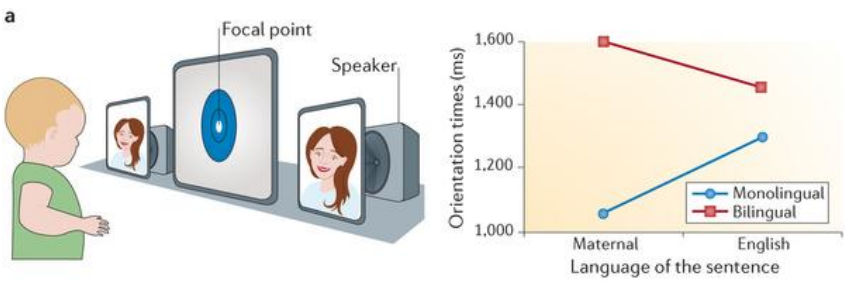

Figure 3. The figure on the left shows the experimental setting to measure the orientation latency. The figure on the right shows the results for the infants tested in the Native-English contrast condition. Reproduced from Costa & Sebastián-Gallés, (2014).

The results showed that, when presented with a Maternal-Foreign discrimination task, the pattern of responses of both groups differed. The results of monolingual infants replicated Dehaene-Lambertz & Houston's (1998) results in which infants were faster to orient to their native language than to a foreign one. However, bilinguals showed an opposite pattern. When comparing between groups, their orientation latencies were only significantly different for their native language as monolinguals oriented faster and bilinguals more slowly towards this language (See figure 3). This pattern of responses was found, being the foreign language English (different rhythmic class) or Italian (same rhythmic class). The authors interpreted that bilingual infants were performing an additional step when presented with their native language, deciding *which* of their native languages it was. However, to date the origin of this difference remains unknown.

Notice that the orientation latency measures familiarity towards the stimuli presented, as from previous studies it was known that infants orient faster towards familiar stimuli (Schonen, Deruelle, Mancini, & Pascalis, 1993). In other studies using the classic familiarization or habituation paradigms, the recover of attention towards a new stimuli is measured, which is not the case in orientation studies.

Taken together, the studies on speech discrimination published to date in the auditory domain does not allow to conclude that exposure to a bilingual input will enhance or hinder language discrimination abilities. More exactly, it may induce different discrimination mechanisms at least towards the native language when learning two very similar languages. A different picture is presented when exploring visual language discrimination abilities.

b) Visual language discrimination

The studies on visual language discrimination examine if infants can use the cues of the faces of speakers to discriminate between languages without the help of auditory information. Weikum et al., (2007) recorded three bilingual French-English women speaking in these two languages. They removed the sound of the videos and presented them to bilingual and monolingual English and English-French infants in a habituation procedure. The authors found that 4- and 6- month-old monolingual infants were able to detect a change in the languages presented. However, at 8 months only bilingual infants could detect it. The results were first explained as reflecting perceptual narrowing, as the bilingual infants tested were native of the two languages tested. However a subsequent study expanded this explanation. Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, (2012) tested if monolingual and bilingual infants who had never been exposed to French and English could detect the change in languages using the same materials and procedure as Weikum et al., (2007). They tested 8-month-old infants who were learning Catalan and/or Spanish and replicated the same pattern of results (See figure 4). Again, bilingual infants were able to detect the change in language, while monolinguals could not. The authors explained their results as an effect of enhanced attentiveness for the bilingual group. An advantage that they claimed to be rooted in the need of bilinguals to keep their two languages separated.

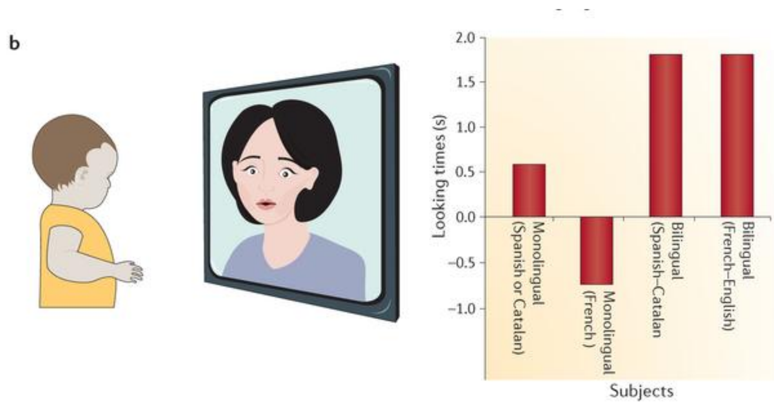

Figure 4. On the left an example of the habituation procedure of the visual language discrimination study is drawn. On the right side the looking times of bilingual and monolingual infants at 8 months of age are shown. Reproduced from Costa & Sebastián-Gallés, (2014).

The studies on visual language discrimination show that, in the absence of auditory information, bilingual infants are able to keep track of visual cues that are present in the visual domain. Such enhanced ability to rely on visual information could help bilingual infants to keep their languages separated. But the studies showing better visual language discrimination in bilinguals have always presented speech in their stimuli (Sebastián-Gallés et al., 2012; Weikum et al., 2007). Therefore, a remaining unanswered question what information do bilingual infants use to discriminate languages: if it is specific articulatory movements present in speech or if infants track other more abstract characteristics of language.

1.4. The utility of neurophysiological measures in language discrimination investigation

A wide range of techniques have been used to explore the developmental brain. From them, two techniques, NIRS and EEG, have been broadly used to explore the brain activity related to language discrimination with an special emphasis on infant populations. Research using NIRS allows the measure of the brain hemodynamic responses related to language processing. May et al., (2011) used NIRS to measure the brain response to native and foreign languages in monolingual neonates. They found a bilateral increase in oxygenated hemoglobin when neonates were presented with their native language and a decrease when the language was from a different rhythmic class. These effects are found with low-pass filtered sentences (which keep the rhythmical structures of language while removing the prosodic and phonetic information) however the effect disappears when languages are played backwards (May et al., 2011).

Minagawa-Kawai et al., (2011) tested the hemodynamic changes in 4-month-old Japanese learning infants when listening to Japanese, English and other non-speech sounds. The two language conditions generated a greater left-hemisphere activation than non-speech stimuli. Also, the native language generated a greater activation than the foreign language. Their results show that the infants' brain responds differently to language than other acoustic stimuli and, clearly, at four months it responds differently towards the native language as compared to a foreign language of a different rhythmic class.

Another technique that has been used to explore the infants' brain response in language discrimination is EEG. Both NIRS and EEG offer some advantages and disadvantages in their use. NIRS offers the possibility of measuring the activation in specific regions of the brain. While EEG is not so accurate in finding the specific source of activity, it offers an accurate timing resolution, which allow us to know in which specific moment different processes take place. The decomposition of the EEG signal into different oscillatory bands allow to measure different cognitive processes that take place in parallel when processing speech.

The only study to date on infant abilities to discriminate native and foreign language using EEG was conducted by Peña, Pittaluga, & Mehler, (2010) who measured the brain oscillations of preterm and full-term infants at 3 and 6 months of age (gestation-corrected age for the pre-term group). Their goal was to know if maturational or environmental factors played a main role in the language discrimination abilities of infants. The pre-term infants at 3 months were equaled in biological maturation age to the 3-month-old full term infants, but in terms of exposure to language, equated the 6 month old full-term group. The researchers presented the infants with sentences in Spanish (their native language), Italian (a foreign language from the same rhythmic class) and Japanese (a foreign language from a different rhythmic class). They found that infants showed an increase in Gamma band oscillations for the native language only. This increase in Spanish in Gamma was different from the two different languages only for the older groups, which they interpreted as evidence of the main role of biological maturational factors to develop language discrimination abilities.

Poeppel (2003) proposes a model of adult speech perception that links the study of brain oscillations at different frequencies with the processing of speech. Some of the models that are based on adult perception suggest that speech is perceived when the cortical oscillations in theta, beta and gamma frequency bands stay phase-locked to the rhythm in the acoustic input (Giraud & Poeppel, 2012; Luo & Poeppel, 2007).

Two recent studies have explored the role of brain oscillations in the processing of native and foreign sentences in adult population. Peña & Melloni (2012) tested the language discrimination abilities of adult Italian and Spanish speakers with a similar procedure as they previously did with infants. The adults were exposed to sentences in Spanish, Italian and Japanese that were played forward and backward. In this case they added a simple task to control that they paid attention to the sentences.

The experimenters decomposed the EEG signal in 4 different bands and related them to the different cognitive processes taking place in parallel in the adult brain when listening to native and foreign speech (See figure 5). Here, the authors reported an increase of the gamma band for the native language only, which they related to the semantic-syntactic unification. The earlier increase of the theta band for native and foreign languages was related to syllabic tracking of the speech stream.

In a more recent study with bilingual Spanish-Basque adults, Pérez, Carreiras, Gillon Dowens, & Duñabeitia, (2015) found a different pattern of oscillations for the native and foreign languages. The authors presented the participants with sentences in Spanish, French (Foreign, unknown) and English (Foreign, known), who were passively listening while completing an orthogonal task. The pattern of results showed an increase in the theta band activity for the native language only and a decrease in the gamma band activity in English only. The authors interpreted the lower activity in the Theta band for the foreign languages as an effect of the higher cognitive cost as compared to the native language. They also argued that participants might be processing the foreign language in small chunks of phonetic and semantic information, which would have lead to a decrease in gamma activity for English only.

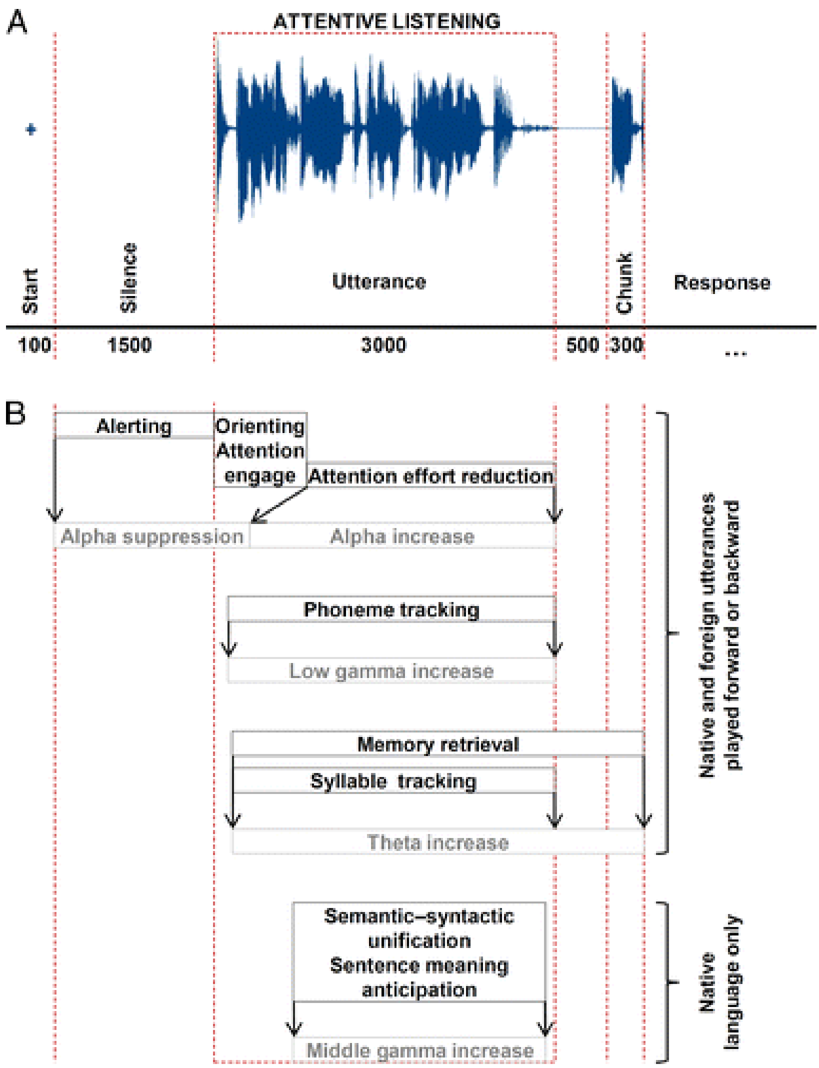

Figure 5. The figure shows the meaning of the changes of the different frequency bands during attentive listening to native and foreign speech in adults. Reproduced from Peña & Melloni (2012)

The study of the oscillatory activity while perceiving language arises here as a powerful tool to investigate the different cognitive processes that take place while discriminating between native and foreign languages. The application to research in infant population seems especially interesting because it allows to extract rich information about cognitive processing while keeping the experiments short and engaging.

1.5. Conclusion

Summarizing, the research on language discrimination abilities of monolingual and bilingual infants finds similar abilities for both groups in the acoustic domain. Bilinguals are not confused about the two languages used in their environment since they can discriminate between them at the same age as their monolingual peers.

First, although both groups of infants discriminate their native language from a foreign one at the same age, at 4 months of age bilinguals show a different pattern of orientation latencies towards their native (spoken) language. Taking into account the literature just reviewed, we hypothesize that bilinguals rely on multiple auditory and visual cues to keep apart their two native languages. Our hypothesis is supported by the studies that have shown that monolinguals and bilinguals exploit differently the information coming from the face of a speaker. When visual information is not present, infants need to rely on auditory information alone and that may represent a harder task for bilinguals, who are used to heavier exploit audiovisual information to process language. Still the origin of the different patterns of orientation latencies of bilinguals and monolinguals when presented with native auditory stimuli is unknown. The use of neurophysiological techniques may allow us to better understand the cognitive processes behind native language discrimination in infants.

Second, bilingual infants show an enhanced ability to extract cues from the visual domain that can help them to discriminate between languages and therefore to build their two linguistic systems. Previous research has shown that this enhanced ability is not specific for the two languages that bilinguals are learning, as they can apply the same strategy to discriminate between two languages they have never seen before. To date, the studies on visual language discrimination cannot explain to which extend this enhanced ability of bilinguals is restricted to identifying articulatory movements to doscriminate languages. An interesting hypothesis worth exploring is that bilingual infants may be better able to process visual regularities that are related to more abstract language properties, and not restricted to speech. The aim of this thesis is to explore these two remaining questions in the field of language discrimination.

1.6. Thesis rationale

Studying language acquisition in bilingual infants provides us with valuable information about how the linguistic environment shapes different language learning strategies. Infants learning two languages since birth receive approximately half of the input from each of their native languages, as the total time they expend receiving language is distributed into two languages. They also have to learn two linguistic regularities but they arrive to their linguistic milestones at the same age as their monolingual peers. To do so, monolingual and bilingual infants will develop specific mechanisms and strategies that will allow them to learn one or two languages.

In this thesis we argue that language discrimination is at the core of the bilingual language acquisition, as, for a bilingual, it emerges as a prerequisite to be able to learn their two native languages. We argue that fundamental differences can be found in the language discriminatory abilities of monolingual and bilingual infants based on the respective linguistic demands of their environments. Here we explore the early language discrimination abilities at two different ages (4 and 8 months) and in two different domains (auditory and visual, respectively).

Chapter two explores the neural origin of differences in auditory language discrimination at 4 months of age. Using EEG, we explore both the temporal (ERP) and time-frequency signal of monolingual and bilingual infants when listening to native and foreign languages.

We find shorter latencies in the ERP signal for monolinguals than for bilinguals when listening to their native language. The results from the frequency domain sheds additional light on the origin of the difference between monolingual and bilingual infants when exposed to their native language. Each group of infants shows a different response in the Theta band, only when listening to their native language. Our results support the hypothesis that native language discrimination represents a higher cognitive demand for bilingual infants.

Chapter three investigates how being exposed to different languages can impact the ability to discriminate languages based on visual informationat 8 months of age. Here we analyze if the enhanced bilingual ability to discriminate visual languages is limited to speech stimuli or if it is extended to more general language properties. Concretely, we expose monolingual and bilingual infants who have never been exposed to sign language to videos of two sign languages. We conclude that the visual enhanced abilities of bilinguals to separate between languages are not restricted to speech. The research also allows to conclude that the information conveyed in the face plays a fundamental role in bilinguals' ability to discriminate languages.

Chapter four presents the conclusions of this thesis dissertation, presents different explanations for the effects found and presents the limitations and future lines of research that will worth being explored.

CHAPTER 2.

COGNITIVE MECHANISMS BEHIND NATIVE LANGUAGE DISCRIMINATION IN BILINGUAL INFANTS

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2.1 Abstract

Discriminating between languages is a pre requisite for language acquisition in a bilingual context. Bosch & Sebastián-Gallés, (1997) showed that, although both bilingual and monolingual infants are able to discriminate between some language pairs at 4 months of age, they show a different pattern of responses than monolinguals for their native language. Their results pointed towards different processing mechanisms underlying language discrimination in monolinguals in bilinguals, whose origins remain unknown. We hypothesize that bilingual native language discrimination is a complex process involving language discrimination and identification. Using EEG, we recorded the brain activity of monolingual and bilingual infants while listening to Catalan (their native/dominant language) and two foreign languages, one from the

same and another from a different rhythmic class. In the early window of analyses we measured the P200 component and in the later window of analyses we measured Theta oscillations. The results indicate that monolingual infants show early discrimination of their native language based on familiarity, while bilinguals perform additional processing related to language identification.

Keywords: infants, bilingualism, language acquisition, speech perception, event related potentials, brain oscillations.

2.2. Introduction

A crucial difference between infants growing up in monolingual versus bilingual environments for successful language learning is that bilinguals need to notice the existence of two language systems in the input, that is, to discriminate the languages in the environment.

Previous studies have shown that although monolingual and bilingual infants[1] show similar language discrimination abilities, (i.e. bilinguals do not seem to be confused by receiving two languages) some relevant differences have been reported too. A well-established fact in the field of language acquisition is that at birth infants, either monolinguals or bilinguals are able to distinguish between some languages, but not between all languages of the world. For instance, monolingual newborns can differentiate between Spanish and English (Moon et al., 1993) or Dutch and

[1] In this article we refer to monolingual or bilingual infants to those exposed to monolingual or bilingual environments (even prenatally)

Japanese (Ramus, 2002), but not between Dutch and English (Nazzi, Bertoncini, & Mehler, 1998). The fact that other animals (such as cotton-top tamarin monkeys or Long-Evans rats) can also make the distinction for rhythmically different languages in particular Japanese and Dutch, (Ramus, Hauser, Miller, Morris, & Mehler, 2000; Toro, Trobalon, & Sebastián-Gallés, 2003) can be an indication that such differentiation abilities may be rooted in ancient evolutionary mechanisms and therefore independent of prenatal language experience.

Theoretical models about such early discriminatory abilities in humans assume that infants primarily rely on information related to prosody. One of the most popular models is the Time and Intensity Grid REpresentation proposal (TIGRE) proposed by Mehler, Dupoux, Nazzi, & Dehaene-Lambertz, (1996). Their proposal suggests that in a first stage, infants would compute the prosodic representation of the speech input. Initially they would perceive rhythmic units based on the vowel nuclei, its duration and intensity as well as the intervocalic duration. Initial discriminatory abilities would be based on these properties. Later, once infants would have more experience with language, they would be able to compute other characteristics of the speech stream that would allow them to make more fine-grained discriminations. This model predicts that at birth infants would be able to discriminate between languages of different rhythmic classes and within-class discrimination would only be possible once their knowledge of language has increased a few months later. Experimental results have shown that the ability to discriminate between languages develops from discrimination of languages from different rhythmic classes at birth to within-rhythmic-class discrimination between 4 - 5 months of age (Bosch & Sebastián-Gallés, 1997, 2001; Byers-Heinlein, Burns, & Werker, 2010; Christophe & Morton, 1998; May, Byers-Heinlein, Gervain, & Werker, 2011; Mehler et al., 1988; Moon et al., 1993; Nazzi et al., 1998; Thierry Nazzi, Jusczyk, & Johnson, 2000; Thierry Nazzi & Ramus, 2003; Franck Ramus, 2002).

The only study to our knowledge with bilingual pre-natal experience in newborns is the one performed by Byers-Heinlein, Burns, & Werker (2010) who showed that English monolinguals and English-Tagalog bilingual infants have no difficulties in distinguishing between these two languages from different rhythmic classes at birth. A different scenario is that of infants growing up in rhythmically close languages that cannot be distinguished at birth. To our knowledge, there is no study investigating the existence of differences between the capacities to discriminate such languages in bilingual newborns. The earliest evidence refers to 4.5 month olds growing up in Spanish-Catalan bilingual homes. Spanish and Catalan are two Romance languages, rhythmically close, but different at other phonological levels (see Bosch & Sebastián-Gallés, 1997 for a more detailed description). Bosch & Sebastián-Gallés (2001) using a familiarization procedure showed that 4.5-month-old Spanish or Catalan monolinguals and Spanish/Catalan bilinguals did not have any difficulty and behaved similarly when these two languages had to be discriminated.

Although monolingual and bilingual infants seem to be equivalently capable of discriminate languages in the first months of life, there is evidence that they may be using different mechanisms. Bosch & Sebastián-Gallés, (1997) reported a contrasting result between both groups of infants when orientation times to the maternal versus an unknown language were reported. Previous studies using this paradigm had shown that infants orient faster towards familiar stimuli (for auditory stimuli see Dehaene-Lambertz & Houston, 1998; for visual stimuli see Schonen, Deruelle, Mancini, & Pascalis, 1993). Following Dehaene-Lambertz & Houston, (1998), Bosch & Sebastián-Gallés, (1997) presented 4-month-old infants with sentences either in the native language (Spanish or Catalan) or a foreign (totally unknown) language. The sentences could appear randomly at the right or the left (non-contingently) from a central location where infants had focused their attention before the sentence presentation. They measured gaze orientation latencies from the central location to the sentence source location. In experiment 1, monolingual infants were faster at orienting to the native language, when compared with a foreign language (i.e. English), therefore replicating Dehaene-Lambertz & Houston's results. However, bilingual infants showed the opposite pattern, they were slower at orienting to the native language, compared to the unknown one. This pattern was replicated in experiment 5, when the foreign language was a rhythmically similar one, namely Italian. The explanation the authors gave to these contrasting patterns was that for bilinguals to orient to the native language, they needed to perform an additional step that monolinguals did not need to perform, that is to identify the familiar language before orientation could be made.

Although this explanation has never been challenged, the differences of orientation latencies can be due to different causes. Yet, behavioral measures cannot inform about different processes happening between the appearance of the stimulus and the infants' response. Electrophysiological measures of the brain activity (EEG/ERPs) can give more precise information about the different intervenient processes and their time-course. These kind of measures have been very useful in investigating the mechanisms involved in speech processing in very young infants (Cheour et al., 1998; Dehaene-Lambertz & Dehaene, 1994; Peña, Werker, & Dehaene-Lambertz, 2012).

The early P200 component of event-related potentials (ERPs) has been associated to processing of familiar properties of the speech stimuli, in infants it is found in the 200 – 250 ms windows of analyses (Picton & Taylor, 2007). A series of studies have investigated the developmental course of the recognition of a familiar voice in newborns, 2-week-olds and 2-month olds (deRegnier, Wewerka, Georgieff, Mattia, & Nelson, 2002; Mai et al., 2012). In these studies, the authors compared the ERP responses to a word pronounced by a familiar and an unfamiliar voice. Newborns and 2-week-olds showed a P200 response that was larger in peak amplitude and longer in latency for the maternal voice than for the stranger's one, suggesting an effect of familiarity. In the case of studies on language discrimination it is expected that infants will show increased amplitude in the P200 for the familiar language when contrasted to foreign ones. Before 5-6 months of age, when the discriminatory abilities are not fully developed, the same amplitude of the P200 component would be found for the native language as for some languages of the same rhythmic class.

The study of brain oscillations, by the decomposition of the EEG signal in different frequency bands, allows identifying different cognitive processes that take place while processing language (see Peña & Melloni, 2012). Relevant to our goals, different studies have related modulations in the Theta and Gamma bands to different aspects of speech perception. The research on adult speech perception suggests that slow acoustic modulations of the speech stream (below 10 Hz e.g. Theta 4-8 Hz) are relevant to the extraction of syllabic and prosodic information. And the perception of fast modulations (equivalent to brain activity in the Gamma Frequency 21-80Hz) corresponds to the extraction of phonetic/segmental information (Luo & Poeppel, 2007; Peña & Melloni, 2012; Poeppel, 2003a). Some studies have related increases in Theta power (4-8 Hz) to the perception of native/non-native contrast in syllables or languages both in adults and infants (Bosseler et al., 2013; Jin, Díaz, Colomer, & Sebastián-Gallés, 2014; Ortiz-Mantilla et al., 2013; Pérez et al., 2015). Interestingly, Theta band can be reduced for native language processing. It occurs in adults, in situations that imply high cognitive demands as in developmental dyslexia (Soltész, Szűcs, Leong, White, & Goswami, 2013) and in normal developing children, as a response towards a deviant syllable in an oddball paradigm (Bishop, Hardiman, & Barry, 2010). To our knowledge, there is only one study that has reported modulations in the brain oscillations in language discrimination in infants. Peña, Pittaluga, & Mehler, (2010) found increases in the Gamma band (55 - 75 Hz) for the native language in infants at 6 but not at 3 months of age which they related to native language discrimination. It is likely that such developmental change may reflect the onset of the establishing of the phoneme repertoire in infants taking place around this age. Ortiz-Mantilla et al., (2013) also reported an enhanced Gamma activity for a native syllabic contrast as compared to a non-native one at 6 months of age, signaling the beginning of phonological narrowing. Considering the previous studies, we hypothesize Theta and possibly Gamma to be potential markers for native speech discrimination at 4.5 months of age.

The aim of the present investigation is to understand the differences in the mechanisms of language discrimination between monolingual and bilingual infants. As seen, the existing evidence on modulations of brain oscillations in early speech processing capacities is quite reduced. An additional complication is that most of the studies have investigated brain responses to short stimuli (such as isolated syllables) with long ISIs. These stimuli facilitate the analysis of the responses, but neither they mimic language in the real world, nor are suitable to study language discrimination. We adapted the procedure of Peña et al., (2010) to measure electrophysiological activity while keeping the procedure as similar as possible to Bosch and Sebastián-Gallés (1997). We compared the neural response of infants towards utterances in their native/dominant language (here Catalan), and two foreign unknown languages: one of the same rhythmic class (Italian) and one of a different rhythmic class (German). As, between 4 and 5 months monolingual infants begin discriminating languages of the same rhythmic class, the current design allowed us to measure the brain response to both kinds of contrasts (within and between class comparisons) in a single experiment.

Bosch and Sebastián-Gallés (1997) observed that both monolingual and bilingual infants were able to discriminate their native language from foreign languages at 4.5 months of age. These authors suggested that bilinguals needed to perform additional processing of the speech stream to identify which of their native languages they were listening to. If Bosch and Sebastián-Gallés (1997) were correct, it should be possible to identify two different types of brain responses corresponding to two different processes. The first process would be the response to familiarity that should be common to monolinguals and bilinguals. The second process would correspond to the additional, cognitive effortful decisional process specific to bilinguals. With this aim we analyzed the processing of the speech stream in two separate windows and extracted the measures appropriated for the analyses in each of them. In the early window (150 – 250 ms), we expected to find greater amplitude of the P200 component for the native language compared to each of the foreign languages. In the late window (800 – 2800ms), we expected to find differences between groups in the brain oscillations for the native language. We expected to find lower Theta power for the native language in the bilingual group. In the high oscillations we analyzed middle Gamma and investigated in both groups if, at this age, it increased in response to the native language.

2.3. Methods

Participants

Twenty-eight 4-month-old infants participated in this study. All infants were full-term with no reported health problems. Twenty-seven additional infants were tested but not included in the final sample due to presenting too many artifacts (20) or crying (7).

An adapted version of Bosch & Sebastián-Gallés' (2001) language questionnaire was administered to establish the infants' language environment. Fourteen infants (7 female) were Catalan monolingual while 14 (5 female) were exposed to Catalan and Spanish, being Catalan the predominant language spoken directly to the infant. Mean exposure to Catalan was 90% (Range 80% - 100%) in the monolingual and 61% (Range 50% - 70%) in the bilingual group.

Infants' age range was between 4:00 and 5:00 months. Four months, 16 days was the mean age for the monolingual and 4 months 14 days for the bilingual group.

The research reported in this manuscript was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee. The infants were recruited from Hospital Quirón and Clínica Sagrada Familia (two private hospitals in Barcelona) and parental consent was acquired before running the experiment. All the families received a diploma together with a t-shirt or a bib as in appreciation for their voluntary participation.

Stimuli

For each language, three female native speakers (i.e., three Catalan, three Italian, and three German speakers) were recorded while they were spontaneously explaining what they were seeing in images for kids. Speakers were instructed to speak so that the sentences would last around 3 seconds. One native speaker of each language checked that the sentences were correct and sounded native.

We selected 18 utterances per speaker that were similar in duration (2,800–3,000 ms) and number of syllables and normalized the amplitude (see table 1).

Table 1. Mean and Standard Deviation of the duration and number syllables per sentence in each of the languages

	Catalan	Italian	German
Mean duration in miliseconds (SD)	2910 (70)	2920 (70)	2930 (70)
Mean number of syllables (SD)	15.21 (1.95)	17.85 (1.88)	16.09 (2.07)
Range nr of syllables per sentence	10 - 19	14-21	11 - 20

Procedure

The procedure was similar to the one used by Peña et al., (2010) in which infants were seated on their parents' lap and watched infant-appropriated images through the screen while the sentences were played through loudspeakers. Brain electrical activity (EEG) was recorded during passive listening to utterances in Catalan (the native or predominant native language), Italian (unknown foreign, same rhythmic class), and German (unknown foreign, different rhythmic class) languages.

A total number of 156 utterances (52 utterances per language) were selected. None of the sentences was repeated during the experiment. Following Peña, Pittaluga, & Mehler's (2010) design, utterances were pseudo-randomly presented in blocks composed of four consecutive utterances per language. Two consecutive utterances from the same speaker or two consecutive blocks from the same language were never presented. Within each block, utterances were separated by 800-ms silent pauses and between block silent pauses lasted between 2,000–2,200 ms. The order of presentation was randomized for each participant. The experiment was paused if the infant manifested discomfort or fuzziness and the study was stopped if the infant started crying.

Electrophysiological recording

EEG signal was recorded with Ag-AgCl active electrodes from 32 scalp locations of the 10-20 system, referenced to the vertex. The signal was amplified using a BrainAmp amplifier (Brain Products GmbH, Munich, Germany) with a bandpass filter of 0.1 - 100 Hz, digitized at a sampling rate of 500Hz. Then a notch filter of 50 Hz and bandpass filter of 1 to 100 Hz was applied offline. The raw EEG signal was off-line averaged and re-referenced to all channels. The peripheral electrodes, which tended to be extremely noisy, were excluded for the analysis.

ERP analysis

For ERPs the EEG data were epoched in 3800 ms time windows ranging from -800 to 3000 ms around the onset of each utterance. A baseline correction was first applied for the pre-stimulus range from -100 to 0 ms. Epochs containing artifacts caused by eye movement were removed using an Independent Component Analysis (ICA). Artifacts were visually removed by independent components (ICs) and their projections on topographic scalp maps (Guerrero et al., 2012). Next, body movement artifacts were also manually rejected by taking into consideration each trial and each channel for each participant. Finally, the spectral activity of each participant was also computed channel by channel and if a channel showed to be noisy, it was removed and interpolated. Four electrodes (F3, FC5, F4, and FC2) localized on the frontocentral region defined our Region Of Interest (ROI). Only participants at least with 10 valid utterances per language (both in ERPs and also in time-frequency) were retained for analysis. To subtract the evoked activity, we applied a vector scaling "within subject" (Urbach & Kutas, 2006) applied separately to each subject's data in the ROI. We performed peak and latency detection in the 150-250 ms window and for each subject measured the amplitude and latency (see supplementary information) of the first positive peak of the window.

Time-frequency analysis

The FieldTrip Matlab© (MathWorks V.R2012b, Natick, MA) package was used for data analysis (Oostenveld et al. 2011). To investigate the Temporal Spectral Evolution (TSE) to characterize gamma-theta oscillatory EEG activity, spectral power analyses were calculated (Hansen et al., 2010). To obtain power spectral estimates in the frequency domain, Fast Fourier Transformation were used for each epoch. Spectral power estimates were then averaged within the Theta (4-8 Hz) and Middle Gamma (55-75 Hz). Sixteen electrodes (F3, FC5, C3, CP1, CP5, P3, F7, FC1, FC6, CP2, CP6, P4, F4, C4, F8 and FC2) localized on the frontoparietal regions defined our Region Of Interest (ROI).

Time-frequency decomposition of all ERPs was calculated using Hanning tappers with length equal to 900 ms (Theta band) and 300 ms (Middle Gamma band). The time-frequency transformed data were then normalized against an 800-ms prestimulus baseline and averaged across (non-contaminated) epochs in the ROI for each infant and for each language. Thus, estimates of signal power contained induced components to stimulus onset (Tallon-Baudry et al., 1999). Normalization consisted in subtracting the power of the baseline from the power of the utterance. Statistical analysis is based on median values, which is the middle score within a data set and is the least affected by outliers. We analized the mean power in the time window between 800 to 2800 ms.

2.4. Results

Event - Related Potentials: P200: *Amplitude*

Planned paired t-test comparisons revealed a significant difference for the monolingual group between Catalan and German ($t(13)=2.31$ $p=0.037$) and Catalan and Italian ($t(13)=3.09$, $p<0.01$) but not between the two foreign languages($t<1$). The same comparison for the bilingual group was marginal between Catalan and German.($t(13)=1.98$; $p=0.06$) and did not reach significance for Catalan and Italian ($t<1$) or Italian and German ($t(13)=1.75$, $p=0.10$). The two groups showed equivalent P200 responses for the native language $t(26)=0.94$ $p=0.35$.

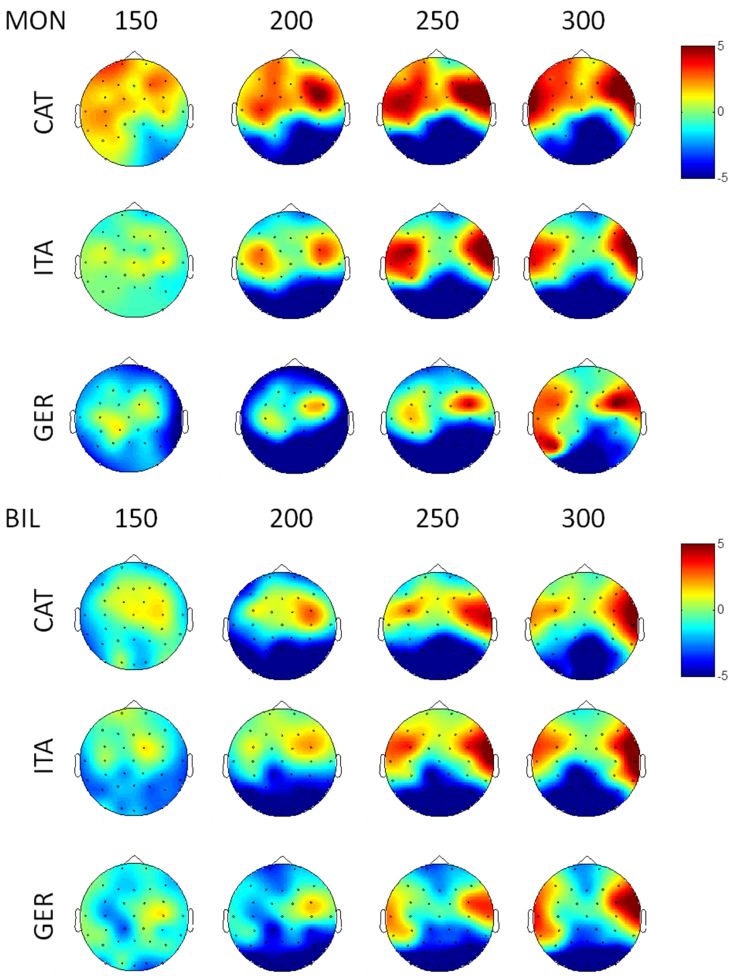


Fig 1. Early ERP components per group and language. The topographic maps represent the time course of the mean amplitude of the early components from 150 – 300 ms after the beginning of the utterances. Each head map represents the mean amplitude of the grand average in the time window beginning at the time indicated by the numerical label plotted on the top and the following 50 ms. The figures on the top represents the response of the monolingual group and on the bottom, for the bilingual group. The languages are plotted on the left side of the figure and the color bar presents the amplitude of the ERP response in microvolts.

Table 2. Mean (SD) of the absolute values of the amplitude in mV of the P200 component.Note that the statistics were done on the normalized values.

	Monolingual	Bilingual
Catalan	5.68 (0.36)	3.47 (0.16)
Italian	3.52 (0.31)	3.71 (0.15)
German	2.8 (0.27)	2.03 (0.36)

Time-Frequency analyses: *Analysis in the Theta band range (4-8 Hz)*

The same planned paired t-test comparisons were applied here. For the monolingual group none of the comparisons reached significance. For bilinguals the difference of Catalan and Italian was significant (t(13)= -2.29 p=0.039) and also the comparison of Catalan and German (t(13)=-2.69; p=0.018) but not between Italian and German .

Planned comparisons between groups for the native language were tested with independent samples t-test analyses and revealed that the differences between groups were significant for Catalan (t(26)= 3.00; p= 0.005) (See Figure 2).

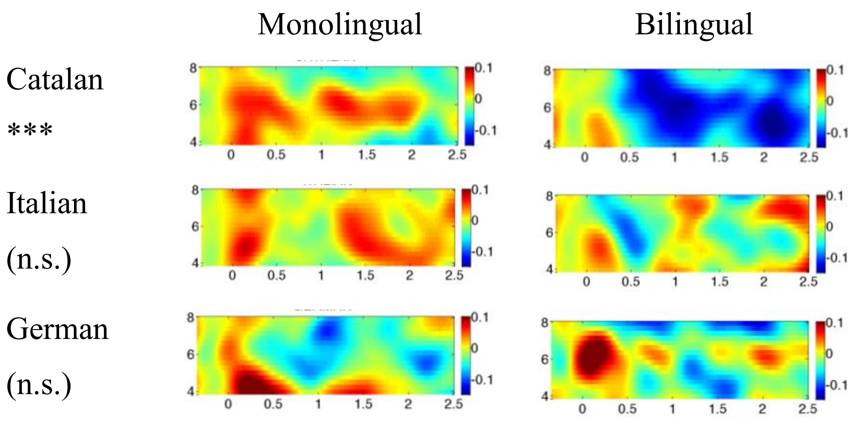


Figure 2. Time-frequency graphs for each group and each of the languages in the Theta-Band range (4-8 Hz) differences between groups are only significant for the native language.

Analysis in the gamma band range (55-75Hz)

We run the same statistical tests as those described for theta band. None of the comparisons approached significance.

2.5. Discussion & conclusions

The current study analyzed the brain electrical activity of 4.5-month-old monolingual and bilingual infants to their native language and two foreign languages. We found greater amplitude in the P200 component for the native language in monolingual infants. In a later window of analyses (800 - 2800 ms) bilinguals showed a desynchronization in Theta band for the native language.

For the early window of analysis (150 - 250 ms), we measured the

P200 component and hypothesized the amplitude to be greater for the native language, reflecting early discrimination based on familiarity. Our hypothesis was based on previous studies that had found a greater amplitude of the P200 component at 2 months of age for the mother's voice as compared to unfamiliar voices (deRegnier et al., 2002; Mai et al., 2012). As expected, monolingual infants showed greater amplitude of the P200 component for the native language compared to each of the foreign ones. Bilinguals showed a marginal difference for the Catalan-German (between class) comparison and the same amplitude for Catalan and Italian (within class). As reviewed before, the discrimination of languages in infancy develops from discrimination of languages of different rhythmic classes to the discrimination of languages of the same rhythmic class. The fact that, at this age bilinguals show the same amplitude of the P200 component for both languages of the same rhythmic class can be reflecting a less developed representation of the native language, likely due to the reduced exposition to it. As bilinguals receive on average half of the speech input from each of their languages, the total exposure to each of them would be smaller than what monolinguals receive. This could lead to a weaker representation of some phonological characteristics of their native language. The marginal difference between Catalan and German is also explained by the weaker neural response to the native language in bilinguals.

We predicted differences between the two groups for the native language, however although the values were in the predicted direction, the analysis did not yield significant differences. We cannot exclude that the lack of differences may be due to a lack of statistical power. Indeed, the variability in the sample was very high (0.36 mV for monolinguals and 0.16 mV for bilinguals) and the sample size relatively reduced (14 participants in each group).

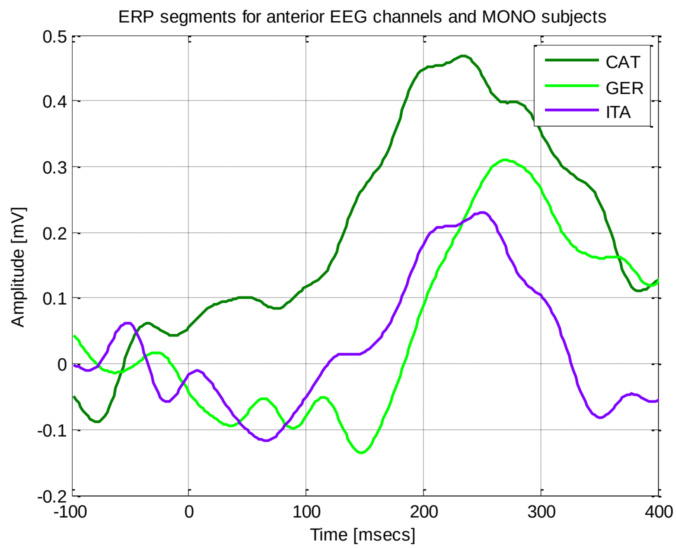
For the late window of analysis (800 - 2800 ms) we measured the brain oscillations in the Theta and middle Gamma bands. We hypothesized that bilinguals would show an additional processing of the native speech in this later window, which would allow them to identify which of their native languages it was. The analysis of the Theta band power showed a desynchronization for the native language that occurred for the bilingual group only. That difference for the native language was significant against each of the foreign languages only in bilinguals and it also reached significance between both groups. Our results mesh well and help explaining the origin of Bosch and Sebastián-Gallés' (1997) previous behavioral results. Lower power in the theta band has been related to processing of different features of the native language in adults and children (Bishop et al., 2010; Soltész et al., 2013). In infants, the desynchronization of the Theta band has been found in relation to modulations of acoustic stimuli that oscillate at the rhythm of suprasegmental linguistic features, such as syllabic and prosodic information (Telkemeyer et al., 2011). We relate the desynchronization of the Theta band to a deeper processing of the suprasegmental information that allows bilinguals to identify which of the native languages is. This complex late processing of the speech signal might be at the basis of the longer orientation latencies for the native language reported by Bosch and Sebastian-

Galles (1997).

The analysis of the oscillations in the Gamma band did not show any significant differences. As far as we know, the only research exploring the neural oscillations of infants in a language discrimination study was run by Peña et al., (2010). These authors found an increase for the native language at 6 but not at 3 months of age in the middle gamma band (55-75 Hz). We did not find differences in the same frequency range and time of interest for any of the groups. We attribute this lack of differences to the fact that in our study infants are younger than the ones where Peña et al., (2010) found modulations in the Gamma band. Peña study infants are younger than the ones where Peña et al., (2010) did not find significant modulations in 3-month-old infants. These developmental changes can have different origins. The first one is maturational, as oscillatory activity shifts from lower to higher frequencies during infant development (Shahin, Trainor, Roberts, Backer, & Miller, 2010). The second one relates to language ability, as Gamma oscillations are related to the extraction of phonetic information in adults and phonological narrowing has been reported from 6 months of age on. Probably, at 4.5 months of age some abilities related to the perception of native phonemes might have started but the representations of the native phonetic repertoire are not strong enough to elicit gamma synchronization (see also Ortiz-Mantilla et al., (2013) for converging evidence in phoneme perception in 6-month olds).

To our knowledge this is the first study showing differences in the oscillatory patterns of bilingual and monolingual infant populations when listening to different languages. Some questions are still open. First, to which extend this effect is characteristic of infants learning two similar languages that are difficult to discriminate. It is possible that the need of making fine-grained discriminations is at the root of deeper processing of the acoustic stream. If this would be the case, bilingual infants learning languages from different rhythmic classes, which are discriminable since birth, might not need additional processing of the speech stream at 4-5 months of age. Second, if the effects reported here are characteristic of the amount of exposure to language of monolingual and bilingual infants. Testing older participants with similar stimuli could answer if with a higher amount of exposure bilingual infants would still need to perform an additional processing of the speech stream. In this case we would expect older bilingual infants to show a similar response as our monolinguals, with a clearly higher amplitude of the P200 component for the native language and no additional theta desynchronization. Finally, although we have not found modulations in the Gamma band, a study with older monolingual and bilingual infants could answer if this rooted on maturation or on exposition. The results of this research show the earliest evidence of neural adaptations induced by bilingualism.

2.6. Suplementary information



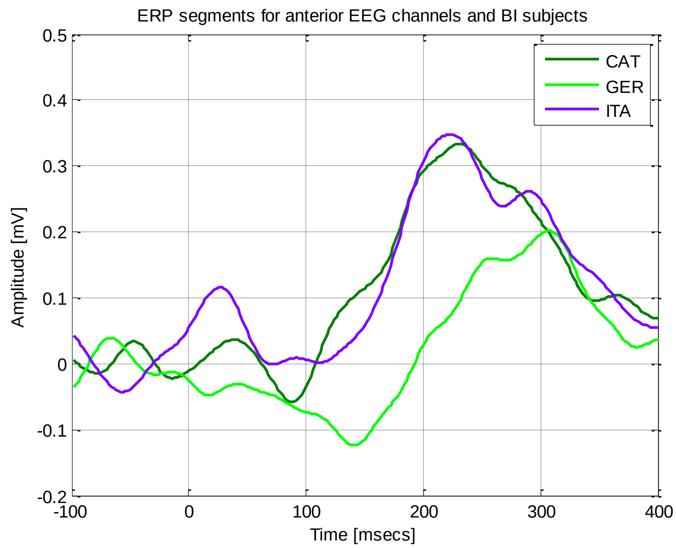


Figure 3. ERP for the monolingual (up) and bilingual (bottom) group towards Catalan (dark green), Italian (blue) and German (light green).

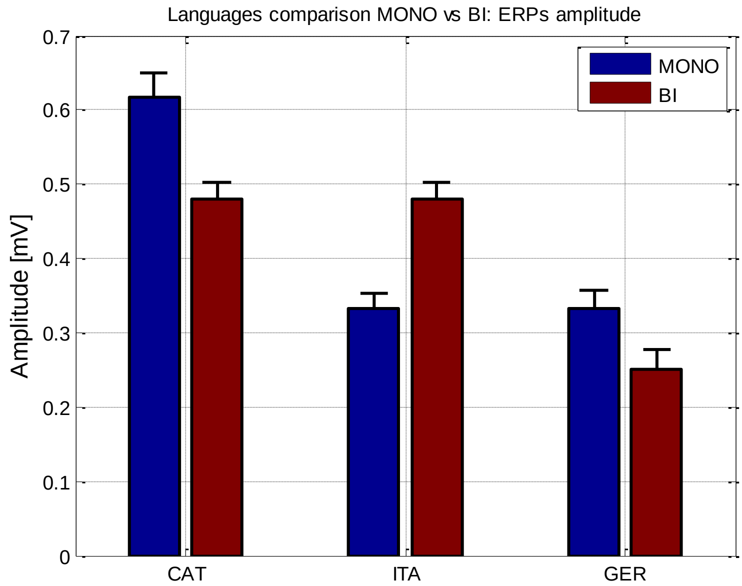


Fig 4. Mean amplitude for the P200 component for each of the languages and both groups Monolinguals are plotted in blue and bilinguals in red. The error bars correspond to the standard error. The values are normalized.

Event - Related Potentials: P200: *Latency*

Planned paired t-test comparisons revealed a significant difference for the monolingual group between Catalan and German (t(13)=-5.18 p<0.001) and Italian and German (t(13)=-2.56, p=0.02) but not between Catalan and Italian(t<1).

The same comparison for the bilingual group did not reach significance for any of the comparisons (all t<1). The difference of the P200 latency between both groups was marginal for the native language t(26)=1.71 p=0.09.

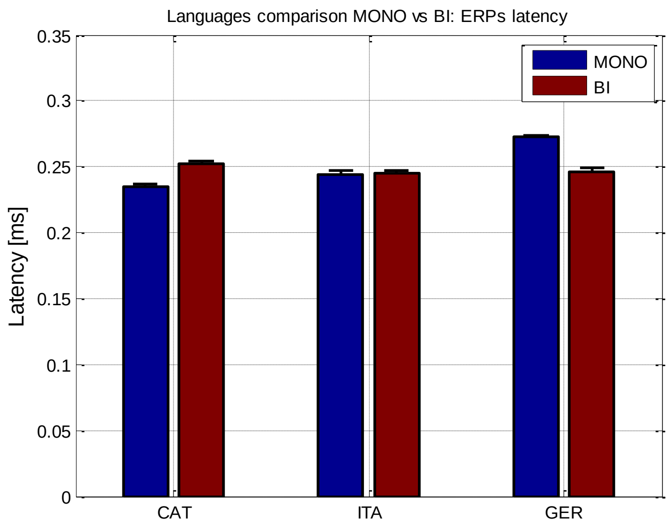


Fig 5. Mean latency for the P200 component for each of the languages and both groups Monolinguals are plotted in blue and bilinguals in red. The error bars correspond to the standard error.

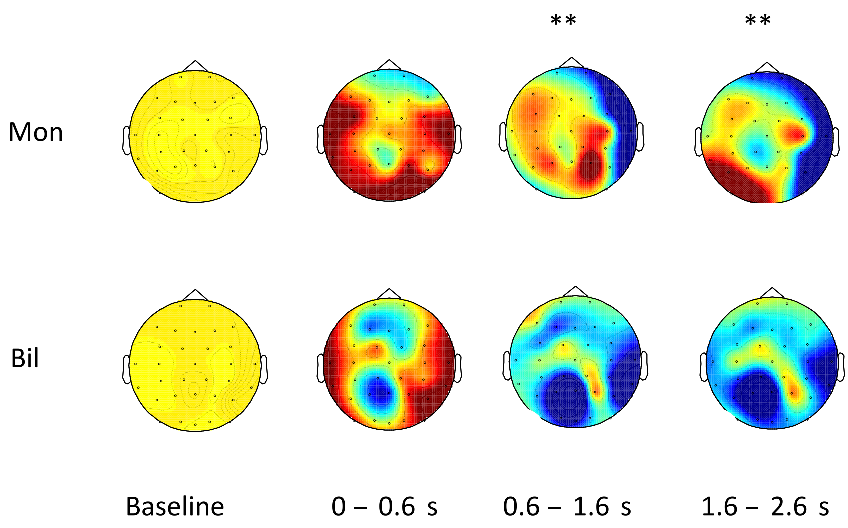


Figure 6. Topoplots of both groups for the native language (Catalan) show the activation of the Theta band in the baseline and during the utterance.

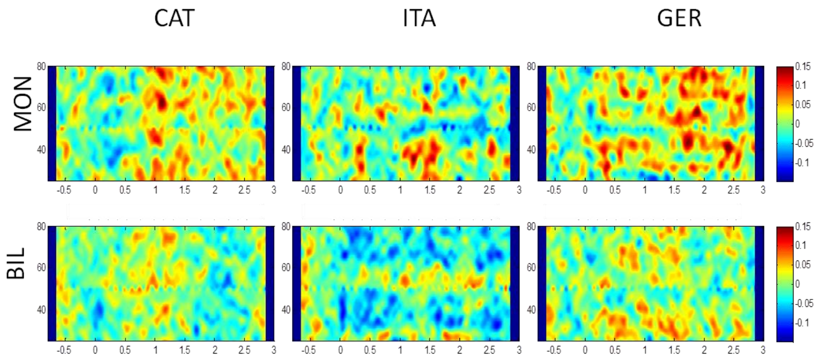


Figure 7. Time-frequency graphs for each group and each of the languages in the Gamma-Band range (21-80 Hz)- No significant differences where found between languages and groups.

CHAPTER 3.

CAN YOU SEE THE DIFFERENCE? THE BILINGUAL ADVANTAGE IN VISUAL LANGUAGE DISCRIMINATION IS NOT SPEECH-SPECIFIC

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3.1. Abstract

Previous studies have shown that 8-month-old bilingual infants outperform monolinguals in visual languages discrimination, even when the languages contrasted are non-native (Sebastián-Gallés et al., 2012; Weikum et al., 2007). Here we test if this enhanced ability of bilinguals is based on a capacity to perceive more general regularities of language, and therefore not restricted to articulatory movements. We tested bilingual and monolingual infants' sign language discriminatory abilities using a habituation paradigm. Our

results show that bilingual infants seem to be able to track linguistic regularities that appear beyond speech. Adult deaf singers could discriminate between the two sign languages, but neither monolingual nor bilingual hearing non-signers could. These results show that experience with sign languages is needed to keep discrimination but that bilinguals lose the capacity in adulthood.

3.2. Introduction

To learn a language, infants must adapt their initial perceptual biases to the specific language/s spoken in their environment. Although little is known about which specific adaptations occur in infants exposed to bilingual input, the need to continuously discriminate between two languages is one of the core and likely first differences between monolingual and bilingual language acquisition.

Different studies have shown that at birth, infants show the capacity to discriminate some pairs of languages, such as Russian and French, Japanese and Dutch or English and Italian, but not any pair of languages, such as Italian and Spanish or Dutch and English (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998). These discriminatory capacities have been linked to sensitivity to differences in the rhythm of languages (Byers-Heinlein, Burns, & Werker, 2010; Mehler et al., 1988; Moon, Cooper, & Fifer, 1993; Nazzi, Bertoncini, & Mehler, 1998; Ramus, 2002). Within a few months, 4-5 month-old infants will be able to discriminate some languages with more similar rhythms, such as English and Dutch or Catalan and Spanish (Bosch & Sebastian-Galles, 1997, 2001; Nazzi, Jusczyk, & Johnson, 2000; Nazzi & Ramus, 2003). Such discriminatory capacities are very similar for infants raised in monolingual environments and infants raised in bilingual environments. However, there is also evidence pointing in the direction that monolinguals and bilinguals may perform different computations when discriminating languages. Bosch & Sebastian-Galles, (1997) measured orientation latencies of 4.5 month old bilingual and monolingual infants towards locations were the native and a foreign language were played. Monolinguals oriented faster to the native language than to a foreign one (as previously reported by Dehaene-Lambertz & Houston, 1998), however, bilinguals showed the opposite pattern. These results indicate the existence of specific adaptations to process the speech signal in bilinguals very early in life[2].

Speech is not restricted to the acoustic code but it involves the processing of the articulatory code. There is ample evidence of activation of motor areas both in speech perception and in speech production (Wilson, Saygin, Sereno, & Iacoboni, 2004). Useful information exists in the visual cues of talking faces even when there is no auditory signal. This redundant information is regularly used even by proficient adults in situations when comprehension is difficult in the form of lip reading (Vatikiotis-Bateson, Eigsti, Yano, & Munhall, 1998). Two studies have tested the ability of infants to

[2] See chapter 2 of the present dissertation

visually discriminate languages by presenting silent videos of the faces of people speaking different languages. The results showed that at 4 and 6 months of age monolingual infants could detect a change in language, however at 8 months only infants growing up in bilingual environments were able to do it (Weikum et al., 2007) even if the infants had never been exposed to the tested languages before (Sebastian-Galles, Albareda-Castellot, Weikum, & Werker, 2012). Studies on adult visual language discrimination abilities have found that to be able to perceive the difference adults need to be native speakers or have acquired early in life at least one of the presented languages (Soto-Faraco et al., 2007; Weikum et al., 2013). These studies indicate the existence of a developmental trajectory in the use of visual information in processing speech and that language familiarity per se is not a decisive factor in explaining bilingual infants' capacities but it is in the case of adults.

A recent set of studies has provided converging evidence about developmental differences in monolingual and bilingual infants' processing of audiovisual speech. There is evidence that from very early on infants can integrate visual and auditory information when perceiving language (Lewkowicz, 2010; Soto-Faraco, et al, 2012). Lewkowicz & Hansen-Tift (2012) showed that in the first year of life infants adapt their gaze by shifting their attention to the eyes towards the mouth area to help them in the process of language learning. These authors presented (monolingual) infants at 4, 6, 8 and 12 months of age audiovisual talking faces. While at 4 months of age, infants predominantly looked at the eyes of the speaker, in the following months their attention shifted to the mouth area, starting to return to the eyes towards the 12th month of life. Pons, Bosch, & Lewkowicz (2015) used a parallel design to compare monolingual and bilingual infants. The results showed that at 4 and 12 months of age bilinguals looked longer to the mouth than their monolingual peers, showing that the period when infants presented a tendency to look to the mouth region was extended in bilingual infants. Ayneto & Sebastian-Galles (2016) have recently shown that the tendency of bilingual infants to pay attention to the mouth region is not restricted to speech stimuli. These authors found that at 8 and 12 months of age bilingual infants looked longer than monolinguals to the mouth region in videos of infants and adults showing different emotions. Altogether, consistent evidence has accumulated showing that bilingual infants exhibit a bias to look more to the mouth region than monolingual infants do during the first year of life. Higher attention to articulatory information present in the mouth area could explain the better discriminatory abilities in bilinguals when presented with silent video clips of talking faces, as in the studies of Sebastian-Galles et al., (2012) and Weikum et al., (2007).

Even if in Sebastian-Galles et al., (2012) infants had no previous experience with the languages tested, they had already had 8 months of exposure to speech. It is likely that by this age, infants have developed a quite sophisticated knowledge of the correspondence between articulators and sounds, so even if presented with unfamiliar languages, they were able to extract a linguistic code, including prosodic (comprising rhythmic) as well as phonemic information. There is evidence showing that 12 month-old bilingual infants are able to simultaneously learn two different rules embodied in three-syllabic stimuli; however monolingual infants are not able to (Kovács & Mehler, 2009). It is therefore possible that in Sebastian-Galles et al., (2012) bilinguals may have built separate representations for the two sets of articulatory movements and use the associated speech codes to discriminate the languages. A second possibility is that infants used more complex language information, such as the rhythm or other types of prosodic cues that face and mouth movements convey. A way of better understanding bilingual infants' capacities is by comparing monolingual and bilingual processing of languages in a non-speech domain.

Sign languages constitute a type of languages that occurs in the visual-manual rather than in the aural-oral modality. Like spoken languages, sign languages exhibit both cross-linguistic similarities and differences in grammatical structure and patterning (e.g., Sandler & Lillo-Martin, 2006). Sign languages exhibit linguistic patterning at phonological, morphological, lexical, syntactic, and discourse levels of structure. Children acquire sign language following the same milestones as observed for spoken language acquisition (e.g. Morgan & Woll, 2002; Newport & Meier, 1985). The linguistic capacity of infants is not restricted to speech and its expression appears in pre-linguistic infants for both modalities: signing and speaking (Petitto & Marentette, 1991; Petitto, Holowka, Sergio, Levy, & Ostry, 2004). Studies on infants babbling have shown that their initial sensitivity to rhythmic patterns appears independently of the modality of language they are exposed to, and therefore it is related to a more general sensitivity towards language structure (Petitto et al., 2004). Like they do for speech over non-speech (Vouloumanos & Werker, 2007), young infants – even those never exposed to sign - show a preference for sign over non-sign gestures (Krentz & Corina, 2008). Hearing infants who have not been exposed to sign language show categorical-like perception of phonetic sign differences at 4 months of age, but by 14 months of age no longer do so (Baker, Golinkoff, & Petitto, 2006) whereas sensitivity to sign is maintained in infants who are raised with a sign language as a first language (Palmer, Fais, Golinkoff, & Werker, 2012). It is important to indicate that phonetic units in sign languages are produced with the hands, a totally different articulator than in oral language. Thus in all the ways it has been examined, studies show that from early in infancy, infants treat sign language as a natural language.

Here we want to test if the advantage of bilingual infants to discriminate visual language information is due to bilinguals' enhanced capacity to track regularities in the language domain in general or if it is constrained to speech processing. We decided to test this ability at 8 months of age as it is the age when differences in visual languages discrimination are found between bilingual and monolingual learners (Sebastian-Galles et al., 2012; Weikum et al., 2007). We hypothesize that bilingual infants, but not monolinguals, will take advantage of their ability to detect visually relevant cues to discriminate between Japanese Sign Language (JSL) and British Sign Language (BSL).

3.3. Experiment 1

3.3.1. Methods

Participants

Twenty-four healthy and full-term 8-month-old infants were included in the final sample. The age range was between 7:16 and 8:28 months. Twelve of these infants (6 female) were raised in a monolingual (Catalan or Spanish) environment (Mean age = 241; days SD=15; range=226-268). The rest of the infants came from a Spanish-Catalan bilingual environment (Mean age = 240 days; SD=14; range=227-265).

A language questionnaire adapted from Bosch & Sebastian-Galles (2001) was administered to assess infants' language background. Bilinguals were exposed to a maximum of 75% of the time to the predominant language. Mean exposure to the dominant language for monolinguals was 92% ranging from 80% to 100% and for bilinguals 66% ranging from 60% to 75%.

Four additional infants were tested but failed to complete the task because of crying (1 bilingual), parental interference (2 bilingual) and not looking to the posttest control (1 bilingual). Additionally, infants who habituated in fewer than 6 (4 bilingual, 3 monolingual) or more than 24 (1 bilingual) trials were excluded from the final analyses.

Participants were recruited by visiting two private hospitals (Clínica Sagrada Familia and Clínica Quirón) in Barcelona, Spain. The research reported in this manuscript was conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee. Before running the experiment, parental consent was always asked and before leaving all the families received a diploma together with a t-shirt or a bib in appreciation for their voluntary participation.

Stimuli

Stimuli consisted of silent video clips of a female deaf bilingual user of Japanese Sign Language (JSL) and British Sign Language (BSL), which are historically unrelated languages. Each clip showed the upper half of the body of the signer, producing two sentences either in JSL or BSL (see figure 1).

The sentences were adapted from those used in the previous neuroimaging study (MacSweeney et al., 2002); where sentences from that study included highly iconic signs which were 'cognate' with ASL signs, the sentences were altered, substituting them with less iconic signs. New JSL sentences were also created that did not have ASL 'cognates'. Fingerspelling was avoided. English glosses for the sentences are given in supplementary information.

For each language a total number of 48 sentences (24 videoclips) were used for the familiarization stimuli. The same sentence could appear in two different trials of the familiarization phase with the restriction that it appeared in combination with a different sentence, and where the same sentence was used more than once, it only appeared in the first position in one of the trials. For the test stimuli 6 new sentences not used in the familiarization (3 videoclips) were presented.

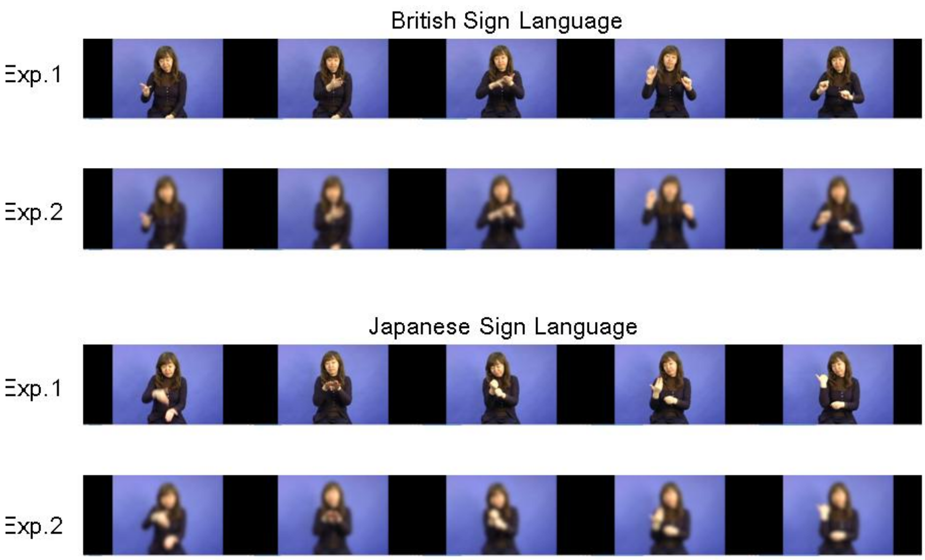

Figure 1. Example of a sentence in British Sign Language (Top) and Japanese Sign Language (Bottom). For each language the first raw represents the clip as showed in the experiment 1 and the second row the same clip as showed in experiment 2 (blurred).

The detailed characteristics of the stimuli in each language are presented in Table 1. The duration was measured from the beginning until the end of each video clip. The number of signs was counted based on the English glosses provided by the bilingual model. A paired t-test analyses confirmed that there were no significant differences between the trials in JSL and BSL in duration (t<1) or number of signs (t<1) in either the habituation clips or in the test clips.

Table1. description of the stimuli

	BSL		**JSL**	
HABITUATION	**Duration (in secs)**	**Number of signs**	**Duration (in secs)**	**Number of signs**
Mean	9.90	9.79	9.95	10.13
Range	6.13-12.09	6 to 13	6.09 - 12.5	6 to 14
Sd	1.66	2.04	2.02	2.38
TEST				
Mean	10.35	9.67	9.83	10.67
Range	9.02 - 11.02	7 to 12	9.25 - 10.15	10 to 11
Sd	1.15	2.52	0.50	0.58

Procedure

We followed a similar procedure as the one used by Weikum et al. (2007) and Sebastian-Galles et al. (2012). Sign language discrimination was evaluated by using a visual habituation paradigm using Habit X 1.0 software (Cohen, Atkinson, & Chaput, 2004).

In each language group half of the infants were habituated to JSL and the other half to BSL. Each habituation trial was composed of two of the 48 possible signed sentences. The habituation trials were always presented in the same order. The habituation criterion was a

60% decrease in looking time at the video on the screen over a sliding window of 3 trials relative to looking times on the trial with the longest looking times. The maximum number of trials presented during habituation was 24. The test phase followed habituation and comprised 6 video clips of the same signer signing in the other language. The same 3 sentences were repeated twice.

During the experiment, the experimenter coded the behavior of the infant online from outside the room, pressing a key when the infant was looking to the screen and releasing it when she was not looking. The experimenter was blind to the change from the habituation to the test phase. Each trial stopped when a maximum of 16 seconds was reached or if the infant looked away from the screen for more than 2 seconds. A colored animation of a waterwheel was presented as a pre-test and post-test to control for the infant's attention. Two independent coders coded infants' recordings offline using the software *PsyCode*. Trials were coded frame by frame (1 frame = 40ms). The high inter-coder agreement was confirmed using a Pearson correlation of all the measures (r=0.93)

Setup and apparatus

The experiment was run at the Universitat Pompeu Fabra Babylab in Barcelona (Spain). During the experiment each infant was sitting on their caretaker's lap in a sound-attenuated laboratory room at 80 cm distance from the screen. The videos were showed on a 27" ASUS-VE276N monitor with 1920 x 1080 pixel resolution. The caretakers wore opaque sunglasses that did not allow them to see what was presented on the screen. Over the screen a hidden *Sony HDR-HC9E* video camera recorded the infant's on-line looking behavior that was projected to a Philips 26PFL2908H/12 22" monitor placed next to the experimenter outside the testing room. A rear mirror was located behind the baby to reflect the materials presented on the screen, which allowed the experimenter to do the offline coding. The experimenter controlled presentation from outside the room using an *Apple Mac Pro*.

3.3.2. Results and discussion

Independent samples t-test analyses comparing the number of trials needed to reach habituation showed equivalent behavior in both groups ($t<1$) Mean Monolingual = 11.25 (SD=5.05) Mean Bilingual = 10.25 (SD=4.03).

Mean looking time to the 2 last trials of habituation was compared to mean looking time during the 3 first test trials for each infant group. We restricted the analyses to the first presentation of the videos to avoid unwanted familiarization effects with the second repetition. Averages for habituation and test trials were 4492 ms (SD=1819) and 5532 ms (SD=3076) respectively for the monolingual group and 4310 ms (SD=1759) and 7980 ms (SD=3193) respectively for the bilingual group (see figure 2). A repeated measures ANOVA with group (bilingual, monolingual) as a between factor and trial type (habituation, test) as a within factor revealed a main effect of trial type $F(1,22) = 10.670$ $p= 0.004$ (*d*=-

1.298) and a marginal interaction of trial type and group F(1,22) = 3.325 p= 0.082.

Planned comparisons showed that only the bilingual group discriminated the two sign languages. Monolingual infants showed equivalent looking times at the end of the habituation test and at the test phase (t(11)=-1.110 p=0.291); however, bilingual infants significantly increased their looking times at the beginning of the test phase as compared to the end of the habituation phase (t(11) = -3.350 p= 0.006).

These results reveal that 8-month-old bilingual infants, but not monolingual infants of the same age are able to perceive a language change between Japanese and British Sign Languages. The fact that previous research has found differences in the face scanning patterns between bilingual and monolingual infants raises the question if it was information present in the mouth area what allowed bilingual infants to discriminate the two languages. Indeed, Pons et al., (2015) observed that during the first year of life, bilingual infants paid more attention to the mouth area than monolinguals. Ayneto & Sebastian-Galles, (2016) also found this pattern in 8 and 12 month olds even when stimuli that did not have any linguistic content (crying or laughing faces). To explore this possibility a second study was run in which the videos were blurred. The use of blurred videos compromised the information coming from the face, while the rhythm of the hands, arms, or body movements was still available**.**

3.4. Experiment 2

The primary articulators for sign language are the hands and arms but the face also conveys important linguistic information. For example, distinct facial expressions, such as raised or furrowed eyebrows, mark the scope of syntactic structures, such as conditional clauses or content (WH) questions (Sandler & Lillo-Martin, 2006; Zeshan, 2006). In addition, signs are produced with different types of mouth movements. In many sign languages, signs are often produced with “mouthings” which refer to mouth movements that originate from the surrounding spoken language, usually a reduced articulation of the spoken translation of the manual sign. Signs can also be produced with “mouth gestures” of various types; in this case, the mouth movements are unrelated to spoken language and may modify a sign (e.g. as an adverbial morpheme) or form part of the phonological representation of the sign (Braem, 2001). Importantly, when comprehending sign language, fluent signers do not track the hands, but rather focus on the face (Agrafiotis et al., 2003; De Filippo & Lansing, 2006; Emmorey, Thompson, & Colvin, 2009; Muir & Richardson, 2005; Siple, 1977).

Given the enhanced attention of bilingual infants for the mouth area in the first year of life, the second experiment tested the hypothesis that bilingual infants used information contained in the face of the signer rather than body movements. To this end, we presented blurred videos (see Figure 1) so that facial information would not be available while rhythm and body movements would still be visible.

If facial cues were helping bilingual infants to discriminate between both sign languages, we expected that they would fail in experiment 2. If, on the other hand, the information they were working with was related to the rhythmic properties of the manual movements of the signer, the same effect should be found in experiments 1 and 2 for the bilingual group.

3.4.1. Methods

Participants

Twelve (7 female) Catalan-Spanish bilingual infants participated in the study. Age range was between 7:22 and 8:21 months. Mean age in days was 247 (SD =9); range= 237-261. Mean exposure to the predominant language was 60% ranging from 50% to 70%.

Infants were counterbalanced by habituation language, order of test and gender. Five additional infants were tested but failed to complete the task because of crying (n=1) and not looking to the posttest (n=3). Two additional infants were tested but not included in the final sample because habituated in fewer than 6 trials.
The participants were recruited from the same private hospitals reported in experiment 1 and the ethical procedure was kept similarly.

Stimuli and procedure

The same video clips as those used in experiment 1 were used; for this study each video clip was blurred with Gaussian smoothing at 50% strength using Final Cut Pro (Apple Inc.). As we only used the

3 first test trials for the analyses in experiment 1, we decided to run the test phase with only three test trials therefore avoiding the repetition.

The procedure and apparatus were the same as in experiment 1. As the inter-coder agreement was high in experiment 1, in experiment 2 the second coder coded the infant's looking behavior for half of the infants, randomly selected. The Pearson correlation was again very high (r=0.99).

3.4.2. Results and discussion

The number of trials infants needed to reach the habituation criterion in this experiment did not differ from those obtained in the previous experiment (t<1); Mean Bilingual Study 1 = 10.25 sec (SD=4.03) Mean Bilingual Study 2= 11.33 sec (SD=5.43).

We ran a paired samples t-test to compare looking times to the last 2 habituation trials and the first 3 test trials. The difference in looking times between the test trial types was not significant (t(11)=-0.517 p=0.616). Mean looking times to the habituation trials was 4110 ms (SD= 1899) and to the test trials 4644 ms (SD=2757).
The critical analysis was the comparison of bilinguals' performance in experiments 1 and 2. We ran a repeated measures ANOVA which showed a significant effect of group F(1,22) = 6.899; p=0.015 (*d*= 0.652), trial type F(1,22) = 7.787 p= 0.011(*d*= -1.08) and an interaction of group and trial type F(1,22) = 4.331 p= 0.049. The main effect of group and trial was due to the increase in looking

times of the bilingual group during the test phase in experiment 1 (see figure 2). Because both groups looked equally during habituation, the interaction is also due to this increase of bilinguals in experiment 1.

Sign language discrimination was not possible when the videos were blurred. The results of Experiment 2 support the hypothesis that bilingual infants' ability to discriminate sign languages is only possible when all natural cues produced are available. We interpret this result as reflecting bilingual infants' increased ability to track cues from the mouth. As reviewed before, bilingual infants show different scanning patterns of faces in linguistic and not linguistic situations (Ayneto & Sebastian-Galles, 2016; Pons et al., 2015) and, likely as a consequence, an enhanced ability to discriminate visual languages (Sebastián-Gallés et al., 2012; Weikum et al., 2007) Although the core of the linguistic information in sign languages is located in the hands and body of the signer, the mouth also conveys supplementary cues. In Experiment 2, we made the information from the face not available by blurring the videos, therefore removing the information that bilinguals used to discriminate sign languages in Experiment 1.

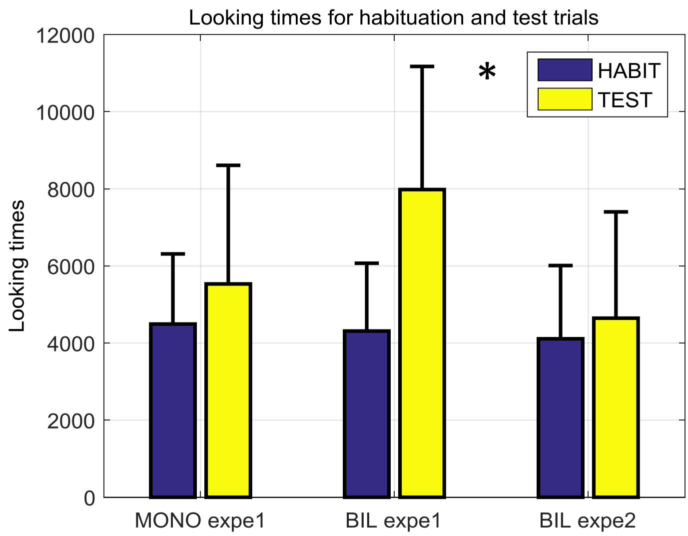

Fig 2. Mean looking times in ms to the last 2 habituation trials (in blue) and the 3 first test trials (in yellow) respectively for the monolingual and the bilingual groups in experiment 1 and the bilingual group in experiment 2.

3.5. Experiment 3

The results of experiment 1 showed that bilingual infants are better at discriminating sign languages when compared to monolinguals. An open question is whether such differences extend into adulthood and how much discrimination capacities depend on experience with sign languages. Previous results with adults in visual language discrimination have proven that this ability is related to both the experience with at least one of the languages of the presented pair and also the age of acquisition of the language. Soto-Faraco et al. (2007) found that Spanish and Catalan monolingual and bilingual adults were able to visually discriminate between both languages while English and Italian monolinguals could not. Weikum et al., (2013) extended these results and found that the ability to distinguish between two visual languages depends on age of acquisition. They found that adults who learned English as a second language could discriminate visual English from French only if they acquired it before 6 years of age. To our knowledge, there is not research showing an advantage of bilinguals processing audiovisual speech in adulthood.

Here we tested a group of monolingual and a group of bilingual adults with no experience with any sign language to explore if the effect of bilingualism is maintained in adulthood. We also tested a group of adult deaf ASL signers with no experience with the two presented sign languages, to assess the discriminability of the stimuli in adulthood. If familiarity with sign languages were necessary to keep this ability we would expect only expert signers to succeed in the task.

3.5.1. Methods

Participants

Twenty deaf signers of American Sign Language (ASL) (8 female; mean age = 34.3 years), 20 English monolingual hearing non-signers (14 female; mean age = 27.4 years) and 20 Catalan-Spanish bilingual hearing non-signers (10 female; mean age = 21.2 years) participated in the study

The ASL deaf signers and English monolinguals were recruited and tested in San Diego (California) and the Catalan-Spanish bilinguals were recruited and tested in Barcelona (Spain).

The majority of the deaf signers were native (n=15) or early (n=3) ASL signers who were exposed to ASL before three years of age. The three remaining signers were exposed to ASL before twelve years of age. All deaf signers had at least fifteen years of signing experience and used ASL as their main language of communication. The deaf signers reported no knowledge of either JSL or BSL, and the hearing participants reported no knowledge of any sign language.

The deaf participants were recruited from within the San Diego Deaf community and the English monolingual hearing participants were recruited from the SDSU community. The study procedures were approved by the SDSU Institutional Review Board. Bilingual participants were recruited from the database of the *Centre for Brain and Cognition* of UPF (http://cbclab.upf.edu/?q=es/node/25). Ethical approval was issued by UPF and informed written consent was obtained from all participants. Bilinguals filled in a detailed language experience questionnaire before recruitment and all of them reported proficient knowledge of both languages, using them in a daily basis and first exposure to both of them before the age of 3. As said, the hearing participants reported no knowledge of any sign language.

Stimuli

The 50 videos of different sentences of the deaf female JSL-BSL bilingual used in experiment 1 were combined to create 25 sentence pairs (5 practice pairs and 20 test pairs). Half of the test sentence pairs were from the same language and half were from a different language. The sentences in each pair were matched in the number of signs (mean number of signs = 4.8; SD = 1.6). Each movie stimuli measured 640 x 480 mm and was presented in the center of the screen with a black background.

Setup and apparatus

The experiment with deaf and hearing American English signers and speakers was run at the Laboratory for Language and Cognitive Neuroscience in San Diego (CA, United States). Catalan-Spanish speakers passed the experiment at the Center for Brain and Cognition at the Universitat Pompeu Fabra in Barcelona (Spain).

Participants were tested in quiet laboratory rooms. Stimulus presentation was controlled by Psyscope X60 software (Cohen, MacWhinney, Flatt, & Provost, 1993).

The videos for the American participants were displayed on a 21.5" iMac monitor with 1920 x 1080 pixel resolution. The videos for the Catalan-Spanish bilinguals were displayed on a 20" iMac monitor with 1680 x 1080 pixel resolution.

Procedure

Before the experiment, participants read the instructions on the screen in English or in Spanish. Each trial consisted of a sentence

pair. Before each sentence a number ‘1’ or ‘2’ was displayed on the screen for 500 ms. The interstimulus interval was a 1000 ms black screen. After the second sentence a question mark was displayed in the center of the screen with a 3000 ms timeout. The intertrial interval was a 1000 black screen. (See Suplementary Information).
While the question mark was on display participants had to respond by pressing a key from the keyboard whether the two sentences were from the same language or from different languages without feedback. Five practice pairs without feedback (two pairs from the same language and three pairs from a different language) preceded the experimental trials. Two different orders of presentation were made and counter-balanced across participants.

3.5.2. Results and discussion

One-sample *t*-tests against chance (.50) revealed that the deaf signers (mean = 58%) were able to distinguish between BSL and JSL above chance, $t(19) = 3.058$, $p = .006$ (d= 1.403). However, the performance of the monolingual (mean = 53%), and bilingual (mean= 52%), hearing non-signers were not significantly above chance: $t(19) = 1.174$, $p = 0.27$ (d=0.538) and $t(19) = 0.767$, $p = 0.45$ (d=0.351) respectively.

The results show that only adult deaf signers who had experience with sign languages but no experience with the languages tested could discriminate between Japanese Sign Language and British Sign Language. Non-signers, either monolinguals or bilinguals, were not able to do so. These results show that to be able to discriminate between two sign languages, experience with this type of languages is needed.

As said above, previous studies with adult speakers on visual languages discrimination had shown that, even when the signers were not native of any of the languages, they could discriminate between them. To be able to visually discriminate two spoken languages, early experience with at least one of them is needed (Soto-Faraco et al., 2007; Weikum et al., 2013). Our results show that this is not the case for sign languages discrimination, at least for the pair of languages tested. Finally, the performance of adult Catalan-Spanish bilinguals revealed that the bilingual advantage in discriminating visual languages is not kept along life.

3.6. GENERAL DISCUSSION

The goal of this research was to investigate if the advantage of bilingual infants in discriminating visual languages was due to general characteristics of language and would be found when non-spoken languages are presented, i.e. in sign languages. In the first experiment we found that bilingual infants were able to detect visually relevant cues to discriminate two sign languages while monolingual infants did not. In Experiment 2, when the video clips were blurred, bilinguals were not able to discriminate between JSL and BSL. In Experiment 3 we tested three groups of adults; deaf expert signers could discriminate between both sign languages while monolingual and bilingual adult non-signers could not.

In experiment 1 we tested the ability of 8-month-old monolingual and bilingual Catalan-Spanish infants to discriminate between JSL and BSL using a habituation paradigm. Bilinguals showed longer looking times in the test phase when there was a change of language, indicating that they noticed the language switch and monolinguals did not. Weikum et al., (2007) found that English-French bilingual infants were able to discriminate between French and English when seeing talking faces with no auditory information available. At 4 and 6 months, monolingual infants were also able to discriminate. The fact that they lost this ability at 8 months and at this age only bilingual infants succeeded was first explained as an effect of perceptual narrowing (previous studies had found perceptual narrowing for correlated visemes, Pons, Lewkowicz, Soto-Faraco, & Sebastian-Galles, 2009). In Weikum et al., (2007) the two tested languages were native for bilingual infants; thus the perceptual narrowing explanation of their results could not be disentangled from a more general effect of enhanced attentiveness in bilinguals. Sebastian-Galles et al. (2012) also found discrimination of visual French and English in Catalan-Spanish 8-month-old bilingual infants, but not in Spanish or Catalan monolingual ones, none of them had ever been exposed to English or French before. Given the low likelihood that the visual phonetic cues differentiating French from English would overlap with those that differentiate between Spanish and Catalan, the authors concluded that perceptual narrowing could not be at the basis of such discrimination. Experiment 1 confirms and expands this interpretation as there is clearly no overlap between the visual cues that differentiate Spanish and Catalan from those that differentiate JSL from BSL. No effect of perceptual tuning can be advocated here and only enhanced attentiveness could explain our results.

The second experiment tested the hypothesis that bilinguals use visual cues from the face of the signer to discriminate between languages as opposed to body (arms and hand) movements. Sign languages are composed of concurrent visual information coming from face and mouth configurations, as well as movements of the hand and body. We kept the same procedure and show the infants the same videos this time blurred so that the movements and rhythm of the hand, arm, and body were still available, but the facial information was clearly compromised. If the information that bilinguals used was in the hands, arms or body, the bilingual infants would have succeeded in discriminating BSL from JSL. The failure to discriminate the languages, leaded us to conclude that facial information contained the critical cues that bilinguals used to discriminate in experiment 1.

We speculated that bilinguals are extracting cues from the bottom part of the face of the signer. Bilingual infants show a bias to look to the mouth of linguistic and non-linguistic dynamic faces (Ayneto & Sebastian-Galles, 2016; Pons et al., 2015). In sign languages, the principal articulators are the arms and hands, but the face also conveys important information (Braem, 2001; Sandler & Lillo-Martin, 2006; Zeshan, 2006). Also the mouth actions (mouthings and mouth gestures) in our stimuli are different for JSL and BSL.

Therefore, addressing attention towards the lower part of the face would allow the bilingual infants to discriminate while removing this information would prevent them from succeeding in the task. Hearing adults increase fixations towards the mouth region when presented with audiovisual stimuli under low intelligibility circumstances, i.e. with noise (Sumby & Pollack, 1954; Vatikiotis-Bateson et al., 1998). It is also important to remark that at 8 months different abilities related to the establishment of the native language are emerging. For example, phonological narrowing for consonants starts to take place in this period (Werker & Tees, 1984), as well as infants start to be able to segment the speech signal into word-like units by computing distributional information (Saffran, Aslin, & Newport, 1996), finally, at this time the beginning of babbling also takes place (Petitto & Marentette, 1991; Laura Ann Petitto et al., 2004). This age therefore seems to be a particularly challenging period in which infants develop different abilities related to native speech. Focusing their attention towards the mouth is likely to provide infants with supplementary coarticulatory information that they can use to learn the language. As bilinguals have the additional cost of developing two linguistic codes, they might pay special attention to the mouth of language producers and that may have helped them to discriminate the two sign languages presented in our study.

The results of experiment 3 confirm that experience with sign languages is necessary to be able to discriminate between two sign languages. We tested 3 different groups of adults, ASL deaf signers, English monolingual and Catalan-Spanish bilingual hearing adults in a JSL-BSL language discrimination task. Here we explored, to which extend the bilingual advantage would be maintained in adulthood Monolingual adult speakers did not discriminate between both languages. This was an expected result, as they had no experience with any sign language. Our results show that the bilingual advantage is not kept along life. To our knowledge, there is not evidence of a bilingual advantage in perception of audiovisual materials in adulthood. Therefore the early advantage of bilingual infants seems to be a mechanism to deal with a complex amount of linguistic information. Later in development, once expertise with language is reached, keeping track of visual cues might not be necessary, at least when language intelligibility is not compromised. Only expert adult signers were able to perceive the difference between languages, even when they were not native with any of them. The results of this experiment work as a control that the two languages are discriminable.

Some questions arise from this investigation. To date, the studies showing a bilingual bias towards the mouth region have been performed with audiovisual stimuli. Although bilinguals show an enhanced ability to discriminate visual languages, there is no evidence of longer looking towards the mouth region (collecting eye-tracking data). It is important to investigate whether infants (and adults) show different patterns of gaze behavior when looking at audiovisual speech (or visual speech). Similarly, an open question is if adult signers are extracting cues to discriminate between both languages from the face of a speaker. Preliminary data from Giezen and Emmorey (in preparation) point in the direction that adult signers do. The use of eye tracker with both, the normal and the blurred stimuli could help to explain the importance of the face of the speaker to discriminate between both languages.

The current research provides evidence that the bilingual advantage in discriminating visual languages in infancy is extended further from the speech domain. Our results indicate that bilingual infants show an enhanced attentiveness to extract and compare cues from an abstract language code.

3.7. Supplementary information

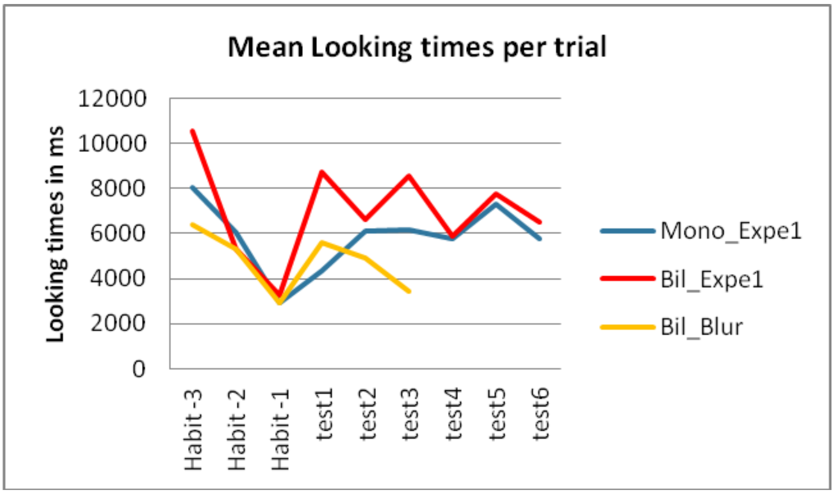

Figure 1. Mean looking times by group to each of the trials analysed.

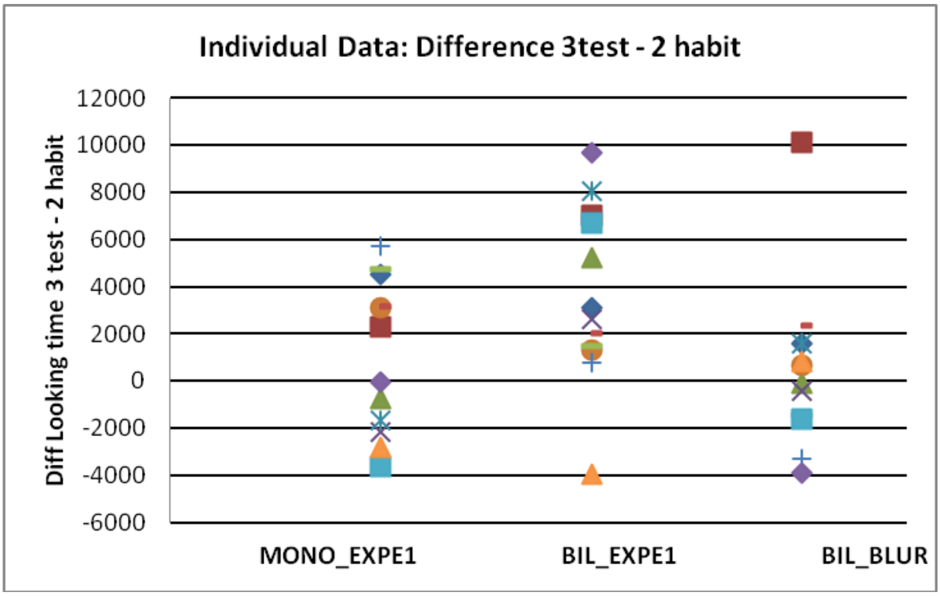

Figure 2. Difference in looking time for the 3 test trials minus 2 last habituation trials. Each data point represents the data of one participant.

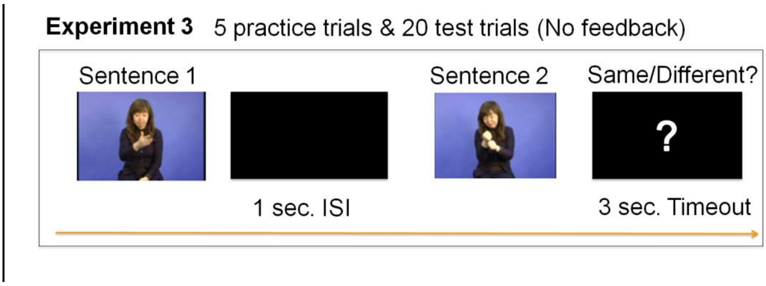

Figure 3. Example of a single trial for the study with adults.

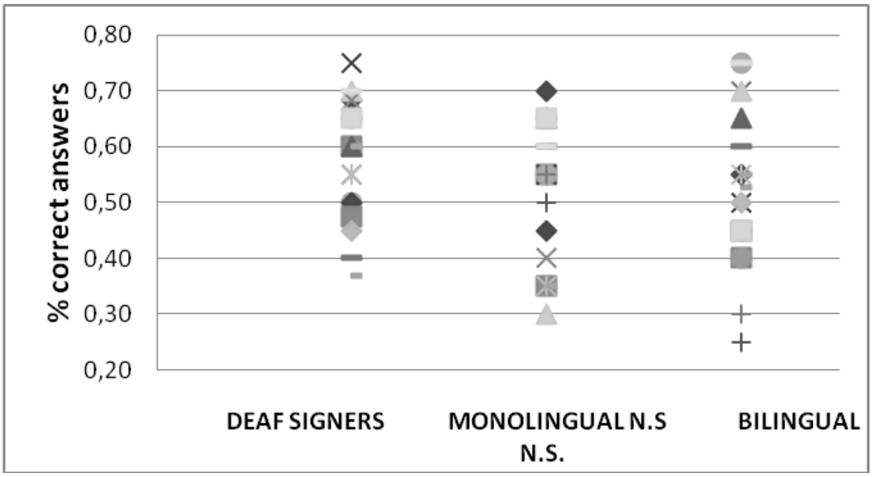

Figure 4. Individual data for the three groups of adults. Each point represents the percentage of correct answers per participants.

CHAPTER 4. CONCLUSIONS

During the first year of life infants face the challenging and fascinating task of acquiring a language. Initially, infants are flexible to learn any specific language or languages. To do so, on one hand, they arrive to the world with perceptual biases that allow them to acquire language and, on the other hand, they grow up in a specific context and exploit the information given there to create the strategies that allow them to learn their native/s language/s.

In this thesis I have explored the concrete case of bilinguals learning Spanish and/or Catalan simultaneously, two languages very similar at diverse linguistic levels as rhythmicity, prosody, phonetics or the lexical level. In the next sections I will summarize the results of this research, the interpretation, the limitations of the present investigation and future questions that arise from it.

4.1. Summary and general discussion of results

In *Chapter two* we analyzed the language discrimination abilities of monolingual and bilingual 4-month-old infants who were learning only Catalan or both Catalan and Spanish. We analyzed the brain activity using EEG while they were listening to sentences in Catalan (their native or predominant language) Italian (a foreign language from the same rhythmic class) and German (a foreign language from a different rhythmic class). Monolingual infants presented higher amplitude in the P200 component for the native language. Bilinguals showed a desynchronization in Theta band for the native language from 800 to 2800 ms.

The motivation for our research came from the results of Bosch & Sebastián-Gallés, (1997) where the orientation latencies towards the native and foreign languages of infants were measured. The authors found different orientation latencies between groups for the native language, where monolinguals oriented faster than bilinguals. When faced with a language discrimination task, monolingual infants only needed to notice if the language played was familiar or unknown, but bilingual infants also needed to figure out which of their two familiar languages was. For this reason, the authors first interpreted that the origin of the differences could be due to the fact that bilingual infants had to perform an additional step when listening to their native language. The longer orientation latencies for this group might be representing an additional processing of the native speech. The aim of our first study was to explore this hypothesis.

We selected two windows of analyses to identify different aspects of the processing of the speech stream. First, we analyzed the ERP P200 component in the 150 - 250 ms window. Based on previous studies, we hypothesize that the P200 component would reflect an effect of familiarity. Therefore we expected the amplitude of this component to be higher for the native language as compared to foreign ones. Monolingual infants showed greater amplitude of this component for the native language in comparison with both German and Italian. The same comparison for the bilingual infants yielded a marginal difference for the Catalan-German comparison and no significant results for the Catalan-Italian one. We interpreted these results as a reflection of a less accurate representation of the features of the native language for the bilingual group.

The ability to discriminate between languages develops during the first months of life. At birth infants can discriminate between languages of different rhythmic classes and around 4 to 5 months of age they can discriminate between languages from the same rhythmic class. As bilingual infants have less exposition to each of their languages, they might have weaker representation of some phonological characteristics. This is why, at this age monolinguals show significantly different P200 amplitude for their native language while monolinguals do not.

We compared the amplitude of the same component for the native language between both groups and found no differences. Although the monolinguals presented greater amplitude for this component than bilinguals, probably the high variability together with a small sample size have contributed to the lack of statistical differences between groups.

We selected a late window of analyses (800 - 2800 ms) to measure brain oscillations in two different bands: Theta and Gamma. If bilinguals showed longer orientation latencies due to an additional processing of the native speech, we expected bilingual and monolingual infants to show a different oscillatory response for the native language in this window of analysis. As expected, this was the case for the bilingual group. We found a desynchronization response for the Theta band for bilingual infants that was significantly different from the Theta power of the foreign languages. Monolingual infants showed the same oscillatory pattern for the three languages. Finally, the comparison of the Theta power for the native language between both groups was significantly different. Modulations of the Theta oscillations have been related to the processing of suprasegmental features of the speech stream. Although increases in Theta power have been mainly reported, decreases in this band of frequencies have also been related to the processing of the native speech in adults under high demanding circumstances, as in developmental dyslexia (Soltész et al., 2013) and the processing of deviant syllables in normal developing children (Bishop et al., 2010) . Importantly, in infants, the desynchronization of low frequencies is related to the perception of modulations of acoustic stimuli at the same rhythm of suprasegmental information (as syllables and prosody) (Telkemeyer et al., 2011)`. Our results expand the knowledge on the bilingual native language discrimination and the origin of the effects in Bosch & Sebastián-Gallés, (1997). We interpret the desynchronization of the Theta band as reflecting a deeper processing of the suprasegmental information. This is the information available at this age to discriminate between languages and emerge as a tool for bilinguals to identify which of their native languages is presented.

Finally we also measured the middle Gamma band oscillations in the same window of analysis and reported no differences within or between groups. Two different reasons can explain these results.

One is maturational and refers to the fact that higher frequency oscillations develop later in life, from the age of 6 months of life on (Peña et al., 2010; Shahin et al., 2010). The other refers to linguistic abilities. While Theta band relates to the perception of syllabic and rhythmic information, Gamma Band has been related to the extraction of phonological information (Poeppel, 2003b) .Although at 4.5 months of age infants might be able to detect some features of the native phonemic repertoire, phonological reorganization has not been reported before 6 months of age (see alsoOrtiz-Mantilla et al., (2013). Therefore we attribute the lack of results in the Gamma band to the young age of our participants.

To sum up, the results of the experiment in Chapter 2 explain the cognitive processing behind early auditory discrimination of monolingual and bilingual infants. Our results show that, to be able to discriminate the native language at 4.5 months of age, bilingual infants display an additional processing of the speech input to identify which native language they are hearing.

The motivation of the studies described in *Chapter Three* comes from previous studies showing an enhanced ability of bilingual infants to discriminate languages in the visual domain (Sebastián-Gallés et al., 2012; Weikum et al., 2007) . To date, all the studies on visual language discrimination compared different oral languages, with which infants had already had 8 months of experience. These studies did not allow us to know if the effect would also be found in absence of speech. Testing sign languages discrimination allowed us to know if the enhanced ability of bilingual infants to discriminate between visual languages would be restricted to speech, or if it would be extended to more general linguistic regularities.

We showed to infants and adults videos of a bilingual signer of Japanese Sign Language (JSL) and British Sign Language (BSL). Following the same procedure as the previous studies with infants, we replicated the same pattern of results found at 8 months of age with visual language discrimination. Bilingual infants were able to detect the change of language but monolinguals were not. In a second experiment, we blurred the videos and showed them to a group of bilingual infants who, in this case, failed to do the task. In the third experiment we tested sign languages discrimination in 3 groups of adults: deaf ASL signers, English monolingual hearing non-signers and Catalan-Spanish bilingual hearing non-signers. Only deaf signers were able to perceive the difference between languages.

Experiment 1 tested the ability of monolingual and bilingual infants to discriminate between sign languages. We used a habituation paradigm similar to (Weikum et al., 2007). Our results showed that, while monolingual infants showed similar looking times in the last habituation trials and in the test phase, bilinguals looked significantly longer to the test trials. This indicates that bilingual infants were able to perceive the change in sign languages while monolinguals did not. The first studies on visual language discrimination were tested on English-French bilingual and English monolingual infants at different ages. The results of bilinguals were first explained as an effect of perceptual narrowing as the English monolinguals could make the distinction at 4 and 6 months but not at 8, when bilinguals could still do it (Weikum et al., 2007).The results with Catalan-Spanish bilinguals who could also make the distinction at 8 months when tested on the same materials expanded this explanation and found that the effect might be due to enhanced attentiveness (Sebastián-Gallés et al., 2012). Yet, bilinguals seem to be better at tracking the visual cues that differentiate two languages. Still after 8 months of experience with faces talking to them, we could not discard that bilingual infants would be better at finding regularities in orofacial movements characteristic of each of the languages. Our results are congruent with the hypothesis that bilingual infants have enhanced attentiveness towards cues that allow discriminating between languages. Importantly, the enhanced attentiveness of bilingual infants in the visual domain is not restricted to their native languages, neither to spoken languages. Instead, it is extended to more general regularities of language.

In Experiment 2 we tested the hypothesis that bilinguals might be extracting the cues from the face of the signer as contrasted to the cues from the body movements (arms and hands). We showed the same videos as in Experiment 1 after a modification that blurred the images. This modification kept body movement but deleted facial information. We tested another group of bilingual infants from the same population, which did not succeed in the task. This indicates that bilingual infants are extracting cues from the face of a language producer to discriminate between sign languages.

The results of previous studies with audiovisual materials guide us to believe that to succeed in our task, bilingual infants use information from the mouth of the signer. Bilinguals exhibit a bias to look to the mouth of dynamic faces, even when they are not producing language (Ayneto & Sebastian-Galles, 2016; Pons et al., 2015). In sign languages, although the main information comes from the hands and arms of the signer, the mouth also contains distinctive information (Braem, 2001; Sandler & Lillo-Martin, 2006; Zeshan, 2002.) that bilingual infants might be tracking to explore regularities in the linguistic code. We hypothesize that bilinguals tend to look longer to the mouth because of the demanding situation of learning two languages. Previous studies with adults have shown that they tend to look longer to the mouth of a speaker under situations that limits the intelligibility of the message (Sumby & Pollack, 1954; Vatikiotis-Bateson et al., 1998). Also, 8 months of age, appears to be a linguistic demanding time when infants are developing several skills to learn language (L A Petitto & Marentette, 1991; Laura Ann Petitto et al., 2004; Saffran et al., 1996; Werker & Tees, 1984). Our rationale is that, during this highly demanding linguistic period, bilinguals , tend to look longer to the mouth because of their challenging task of learning two languages. Monolingual infants might not do it in non-linguistic situations, as in Ayneto & Sebastian-Galles, (2016) and due to the lack of experience with signs, they might not do it when dealing with sign languages. However, bilingual infants might implement this ability in front of any dynamic face and that would have helped them to track the necessary cues to discriminate the languages.

In the third experiment we tested three groups of adults in the discrimination of JSL and BSL, as a control for the previous results. A group of monolingual and bilingual hearing non-signers and a group of deaf signers. Monolingual English speakers and Catalan-Spanish non-speakers were not able to perceive the difference. Deaf signers, who were not native of any of the languages of the study, were able to perceive the difference. The results of monolingual and bilingual non-signers show that the bilingual advantage is not maintained along life. As deaf signers were able to discriminate between JSL and BSL, evidence is given that these two languages are discriminable. Therefore the bilingual advantage seems take place in infancy, when the processing of language is specially challenging. In adulthood, after wide expertise with language is reached, the necessity to pay attention to visual cues that define regularities of languages might not be necessary. With it, the ability to discriminate between an abstract linguistic code is not kept, unless wide experience with this linguistic modality is given.

Bilingual infants develop an enhanced ability to keep track of visual cues to discriminate between languages. The results described in *Chaper three* provide evidence that this skill is not restricted to speech stimuli and therefore, bilingual infants have an especial ability to extract cues that define the characteristics from an abstract linguistic code.

4.2. General discussion

In this thesis I have focused in a characteristic of bilingual environments that is the necessity of keeping languages apart. As stated before, infants are born with certain biases for language perception and develop the necessary mechanisms to learn the language/s from their environment. Here, we studied some necessary adaptations of bilingual infants at two points of development and in two different domains during the first year of life.

Previously literature had shown that the timing when monolingual and bilingual infants show different discriminatory abilities was the same. Based on previous literature, we hypothesized that bilinguals would use multiple auditory and visual cues to separate their two native languages. If so, discriminating their native language based on acoustic information alone (i.e. in absence of visual cues) would represent a harder task. By using electrophysiological measures we could show that, at 4.5 months of age, monolingual and bilingual infants rely on different cognitive strategies to decode their native speech input. Our data shows that bilingual infants need to process the native language more deeply than monolinguals and we speculate that the representation of their native language is not so strong due to less exposure. This investigation explains the origin of the different responses of bilingual and monolingual infants when confronted with a language discrimination task.

Following the rationale, if bilinguals used multiple cues from the visual and acoustic domains to keep their languages separated, one would expect an enhanced ability to extract visual cues to discriminate languages. One question that was unexplored was if the linguistic enhanced ability to discriminate visual languages would be restricted to speech or if they would be able to extract more general linguistic cues. Here we provide evidence that bilingual infants extract visual cues from an abstract linguistic code.

4.3. Future lines of research

A remaining open question is if the effects reported here are characteristic of bilingual infants who learn two similar languages. The perceptual abilities of infants develop within the first year of life. If the two languages in the environment are similar at linguistic levels that develop later (i.e. they share rhythmic class or overlap at phonological level) the discrimination of them might be more demanding during the first months. An open question worth exploring is how the linguistic background of bilinguals interplays with their early discriminatory abilities. If the reported results are characteristic of a bilingual population learning two languages from the same rhythmic class (i.e. more difficult to discriminate), we would expect bilingual infants exposed to languages from different rhythmic classes, to show a different oscillatory brain activity for their native language. In the case of visual language discrimination, the pair of languages learned does not seem to affect, as similar results have been found with infants learning English and French or Catalan and Spanish (Sebastián-Gallés et al., 2012; Weikum et al., 2007). Additionally, as in our visual languages discrimination, the languages contrasted were foreign for all the infants; we would expect bilingual infants to behave similarly in these tasks independently of their native languages.

In the acoustic language discrimination, future research should explore how amount of exposure to language is reflected in the different brain markers. In this thesis we claimed that the pattern of ERP responses of our bilingual group was reflecting a less developed brain response due to less exposure to their native language. If this is the case, testing older and younger monolingual and bilingual participants could shed some light on the development of brain markers for language discrimination and the comparison among them would explain particular role of speech exposure in development.

It is also important to investigate the development of the bilingual bias towards the mouth with visual dynamic faces, using eye-tracker. This could answer the question if the enhanced ability of bilinguals to discriminate between visual languages is due to a bias towards the mouth. It would be also interesting to know if infants show different gaze patterns when exposed to audiovisual or to visual stimuli.

4.4. Final statement

Learning language is one of the most fascinating achievements of infancy. In this thesis we have explored a peculiarity of bilingual context, the need to discriminate between languages. The results of this thesis enrich the knowledge of language acquisition to date with fruitful data about how infants deal with their linguistic environment to develop the tools that allow them to successfully learn language.

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