The role of experience in perceptual reorganization

The case of bilingual infants

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“In expanding the field of knowledge we but increase the horizon of ignorance.”

Henry Miller

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To all the families who selflessly collaborated with science.

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who should be forced to read it.
Ten times.
Without breaks.

Seriously, both were equally valuable lessons.

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ABSTRACT

Newborns are able to perceive sound of many languages. However, throughout their first year of life, both biological maturation and language exposure attune infants' perceptual systems to the characteristics of their native phonetic repertoire(s). After perceptual reorganization such initial sensitivities are either lost, maintained or sharpened.

In order to assess how much and what kind of exposure drives phoneme acquisition, we compared monolingual and bilingual infants from 7 to 18 months on discrimination of nonnative contrasts and on consonant production. First, our results show that bilingual infants maintain the capacity to discriminate nonnative consonants for 6 additional months compared to monolinguals. Second, enhanced discrimination correlates with higher babbling rates and more accurate consonant productions in bilinguals. Third, the degree of bilingualism predicts these results at specific stages in development. Our findings open a new set of interpretations regarding the role of linguistic experience, attention and maturation in perceptual reorganization.

RESUMEN

Los bebés recién nacidos son capaces de percibir sonidos de muchos idiomas. No obstante, durante su primer año de vida el desarrollo biológico y la experiencia lingüística moldean sus sistemas perceptivos adaptándolos a las características de su repertorio fonético nativo. Pasada la reorganización perceptiva, sus capacidades iniciales se pierden, se mantienen o se afinan. Con tal de averiguar qué cantidad y qué tipo de experiencia es necesaria para la adquisición fonética, comparamos la discriminación y producción de consonantes no nativas en bebés monolingües y bilingües desde los 7 hasta los 18 meses. En primer lugar, nuestros resultados muestran que los bebés bilingües mantienen la capacidad de discriminar consonantes no nativas 6 meses más que los bebés monolingües. En segundo lugar, solo en los bebés bilingües, la mayor discriminación correlaciona con más balbuceo y con más precisión al producir consonantes nativas. En tercer lugar, el grado de bilingüismo predice los resultados en etapas específicas del desarrollo. Nuestra aportación abre un nuevo abanico de interpretaciones acerca de qué papel juegan experiencia, atención y maduración en el proceso de reorganización perceptiva.

PREFACE

Linguistically competent human adults are able to extract the relevant properties from their very complex and varying acoustic environment to finally represent meaning. Research in the field language acquisition aims at determining when and how infants become such mature language users.

Nearly half a century of research in the field of developmental science has been trying to disentangle what in the unique language capacity observed in adults is developed and what is learned.

From birth, infants sort and parse linguistic regularities from their linguistic input and, by doing so, their perceptual systems adapt to match the properties of their native language. In turn, this perceptual foundation is crucial to a cascade of other processes required to acquire a whole set of complex linguistic skills. Hence, the perception of the minimal units that constitute infants' native language are of fundamental importance for language acquisition.

Both maturation and experience play a crucial role in phoneme acquisition and bilingualism provides the perfect scenario to assess how the two factors interact. By comparing perceptual reorganization in monolingual and bilingual infants we can study the role of linguistic experience while controlling for maturational age.

During these years we tested the decay of nonnative sound discrimination in both populations to assess the process of perceptual reorganization and simultaneously equalize for phoneme frequency. Due to the unique properties of the Catalan-Spanish bilingual population, we could conduct novel and more informative analysis than seen in similar previous studies. Furthermore, the implementation of a technique widely used in the literature allowed us to keep a foot in the past and to simultaneously step ahead. On the one hand, with the classic visual habituation procedure we could set a ground for comparison between our results and previous results with other languages. On the other hand, the analysis of infants' productions during the discrimination task upgraded the classic experimental design with richer exploratory tools.

Hence, this dissertation contributes to the field of language acquisition not only with provocative findings but also with the validation of new methodological implementations.

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1. INTRODUCTION

1.1. Initial biases for language

Infants become proficient language users at around their third birthday. Moreover, they learn language effortlessly. Regardless the complexity, the noise and variability present in the linguistic input, infants extract relevant information from different voices, accents, dialects and individual speaker variability (Schmale, Cristia, Seidl, & Johnson, 2010). Fortunately, infants are born with some initial language sensitivities. Newborns show a preference for natural speech in comparison to non-speech analogues (Vouloumanos & Werker, 2007), filtered speech (Spence & DeCasper, 1987), backwards speech (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Pena, Bedore, & Rappazzo, 2003), and equally complex synthesized sounds (Vouloumanos, Hauser, Werker, & Martin, 2010). At birth, infants prefer to listen to their mothers' voice than other female voices (DeCasper & Fifer, 1980; Mehler & Bertoncini, 1978; Spence & Freeman, 1996) although they are also able to detect differences between non-familiar voices even in the context of minor prosodic information (Floccia, Nazzi, & Bertoncini, 2000). They also prefer to listen to their native language (Moon, Cooper, & Fifer, 1993) and discriminate the difference between their native and other languages (Mehler et al., 1988). Furthermore, they detect the difference between two nonnative languages if such languages are rhythmically distinct (Nazzi, Bertoncini, & Mehler, 1998; Ramus, Hauser, Miller, Morris, & Mehler, 2000). In addition, newborns can detect more detailed aspects of language, such as word boundaries (Christophe, Dupoux, Bertoncini, & Mehler, 1994), stress patterns within words (Sansavini, Bertoncini, & Giovanelli, 1997) and structure regularities (Gervain, Nespor, Mazuka, Horie, & Mehler, 2008). Neonates can differentially discriminate canonical versus non-canonical syllabic distinctions (Moon, Bever, & Fifer, 1992) and they can also track perceptual cues in the input to distinguish lexical from grammatical word categories (Shi, Werker, & Morgan, 1999).

1.2. Categorical perception

Infants also have the ability to categorize sounds from the acoustic signal into phonemes, the language minimal units. Such perceptual phenomenon is called categorical perception and was initially studied in adult populations (Liberman & Harris, 1957). Categorical perception allows listeners to cope with irrelevant acoustic differences such as speakers variability (Kuhl, 1979) or speaking rate (Miller & Dexter, 1988), and thus to recover words and their meanings rapidly when listening to others speak. Lieberman et al. (1957) initially demonstrated three major findings. First, when adult listeners are asked to label tokens from a VOT continuum between one stop consonant to another, participants agree in which category they should classify such tokens. Second, they succeed at discriminating speech sounds that belong to different phonetic categories in their native phonetic repertoire but they perform poorly at discriminating those from the same category, even when the physical distance between tokens is equated in both conditions (Liberman & Harris, 1957). Third, subjects' performance at categorizing sounds predicts discrimination, which sets proficiency in discrimination as a valid measure for phoneme identification.

Since assessing identification in preverbal infants is methodologically complex but measuring their discrimination abilities is methodologically feasible, infants' phoneme perception is commonly studied by evaluating their performance at sound discrimination. Although infants are capable of distinguishing within phonetic category distinctions (McMurray & Aslin, 2005) at birth infants show enhanced discrimination for some between category differences than within category differences (Dehaene-Lambertz & Dehaene, 1994; Werker & Lalonde, 1988). Eimas et al. (1971) first showed that, in line with the Lieberman et al. (1957) adults' data, infants fail to discriminate consonants from the same voicing category but succeed at cross-category discriminations. More recently, Eimas and colleagues behavioral findings have been corroborated with functional optical imaging data. Mahmoudzadeh et al. (2013) found that even at the very onset of the establishment of a cortical circuit for the auditory system, preterm infants show larger brain responses to changes crossing a phonetic boundary than to acoustic deviants within the same category. In addition, studies with sleeping neonates have posited that, regardless of attention, infants' brains react with electrophysiological responses to a change in phoneme even in the presence of irrelevant speaker variation (Dehaene-Lambertz & Pena, 2001).

In sum, the conjunction of such early innate and learned biases for language project human infants on a pathway for language learning beyond the more discrete capacities available to other animals.

1.3. Perceptual reorganization

However, infants' initial language capacities are not equivalent to the linguistic capacities observed in adults. Adult language users are better than infants at processing specific language patterns relevant to their native language (Miyawaki et al., 1975) and, simultaneously, they are less proficient (Flege, 1992) and less permeable to learn sounds of foreign languages even in the cases of early but limited language exposure (Bosch, Costa, & Sebastián-Gallés, 2000; Burfin et al., 2014; Holzen & Mani, 2012; Johnson & Newport, 1989; Logan, Lively, & Pisoni, 1991; Pallier, Bosch, & Sebastián-Gallés, 1997; Sebastián-Gallés & Soto-Faraco, 1999; J. F. Werker, Gilbert, Humphrey, & Tees, 1981).

Studies with electrophysiological data (Cheour, Haapanen, & Ceponiene, 1998; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005) and meta-analysis performed on a wide range of behavioral studies

(Tsuji, Bergmann, & Cristia, 2014) describe an inverse correlation between infants' timing of acquisition of native sound categories and the decay in discrimination of nonnative contrasts. Hence, in order to acquire their native phonetic repertoire, infants lose sensitivity to most contrasts that are irrelevant in their native phonetic repertoires, they maintain and sharpen the representations of their native phonetic categories, and they acquire new sounds that are not initially perceived throughout repeated exposure.

The process of perceptual attunement to the native phonetic categories during the first year of life is commonly known as perceptual reorganization or perceptual narrowing. The changes in infants' perceptual systems during this period have been widely studied as a means to understanding how much and what kind of exposure is needed in order to acquire the native phonetic repertoire and to what extent biological factors also contribute to the process of phoneme acquisition.

1.3.1. The role of linguistic experience

1.3.1.1. Learning by forgetting: loss of sensitivity to nonnative contrasts

The first study to explore the development from infants' initial perceptual biases to the phonetic perception of adults was conducted by Werker et al. (1981). Their results showed that English monolingual adults were not able to discriminate the difference between their native dental contrasts and Hindi nonnative retroflex contrasts, neither for the dental aspirated plosive /tha/-/Tha/ nor for dental unaspirated plosive /ta/-/Ta/ consonant conditions. In contrast, 6 to 8 month-old English monolingual infants, despite the equal absence of exposure to Hindi, showed initial discrimination of nonnative sounds, performing like adult Hindi monolingual speakers who had been exposed to those sounds from birth. Crucially, an additional condition tested English monolingual adults on discrimination after training them on discrimination to such contrasts. The results revealed that after the training they improved their performance but their discrimination skills were still poor in comparison to 6 month-old English infants and to native Hindi speakers.

Werker and Tees (1984a) conducted a second relevant study, in which they tested English infants on Hindi and Salish contrasts throughout their second semester of life, at 6-8 months, 8-10 months and 10-12 months. The results revealed that their discrimination of nonnative sounds progressively decreased across time, regardless of the type of contrast being tested, until infants finally ceased to discriminate by 12 months. However, Hindi and Salish infants at 12 months, who were exposed to their respective native contrasts, maintained the discrimination patterns by 12 months of age. Altogether, the results of both studies suggest that infants are born with some broad-based perceptual sensitivities. However, exposure to their native language modifies their initial perceptual abilities and gradually attunes them to the specific characteristics of their native language. Only around their first year of life, will they match the perceptual skills of the adults in their environment. Furthermore, such perceptual modifications cannot totally be reversed in adults even in conditions of additional training to nonnative sounds, suggesting that early language exposure has long-lasting effects on the perceptual system. The same phenomenon has been observed in vowel discrimination studies. At 4 months of age, Spanish infants can discriminate the /e/–/ɛ/ vowel contrast that is used in Catalan but not in Spanish, but they lose discrimination to such contrasts by 8 months (Bosch & Sebastián-Gallés, 2003).

1.3.1.2. Maintainance of initial contrast sensitivities

The attunement theory by Aslin & Pisoni (1980) suggests that discriminative capabilities that are partially present or broadly specified in early development are maintained or sharpened by relevant linguistic experience.

Kuhl et al. (1992) showed that by 6 months of age, language experience has already shaped infants' perception of vowels. In their study, Swedish and English infants were tested on two different vowel prototypes, the English /i/ and the Swedish /y/. Their results revealed that when infants were presented with different variants for each of the two vocalic sounds, they equated the variants to the prototype more often for their native category than for the foreign language vowel category. That is, the more frequent sounds in infants' environment attracted non-prototypical sounds stronger than novel foreign sounds. The authors named this perceptual preference of assimilation of deviants to the native category the perceptual magnet effect. Their results demonstrate that infants' representation of native vowel categories is influenced by their specific language experience already by 6 months, resulting into the phonetic representation of native phonetic prototypes.

Conversely, Best et al. (1987) showed that for some contrasts, the assimilation of nonnative sounds to native categories does not occur. More specifically, they tested English adult and infants on the discrimination of foreign Zulu Click consonant contrasts and their results revealed that both infants and adults succeed at discriminating the nonnative sounds. Hence, linguistic experience does not always correlate with a loss of discrimination. Their Perceptual Assimilation Model (Best, 1994) suggests that the assimilation of nonnative sounds to native sound categories will only take place when the native and nonnative contrasts are produced using the same articulatory organs, or else, they will either be perceived as uncategorized speech sounds, or as non-speech sounds. In line with the PAM theory, Polka & Bohn (1996) conducted a study with English and German infants and reported that the directional asymmetries found in vowel perception suggest that vowels produced with extreme articulatory postures may serve as perceptual attractors in infant vowel perception.

1.3.1.3. Enhancement of initial contrast sensitivities

Patricia Kuhl and colleagues (2006) tested English and Japanese infants on the syllables /ra/-/la/ before and after perceptual narrowing, at 6 and 12 months. The consonants /r-l/, is a native phonetic contrast for American speakers and a nonnative contrast for Japanese speakers (Miyawaki et al., 1975; Tsushima, Takizawa, Sasaki, & Shiraki, 1994). Both groups showed discrimination at 6 months. However, English infants improved their discrimination at 12 months while Japanese infants showed a decline in discrimination at the same later age. Again, infants' discrimination abilities depended on infants' native language exposure. In the case of English infants, native language exposure not only maintained but also facilitated their discrimination of native contrasts, as has also been reported by Tsao et al. (2006) on a study testing English and Mandarin infants on affricate-fricative contrasts.

Maye et al. (2002) claimed that the statistical analysis of phoneme distributions available in speech input drives the enhancement of the representation of native phonetic categories. The authors found that two sounds which are discriminable in early infancy were no longer discriminated by infants who had been familiarized, for only two minutes, to the sounds within a unimodal distribution. A follow up study (Maye, Weiss, & Aslin, 2008) exposed infants to a bimodal distribution of speech sounds and after familiarization infants showed enhanced discrimination of a difficult speech contrast. Together, their results suggest that exposure to bimodal distributions of sounds result in enhanced discrimination, while exposure to unimodal distribution of sounds results in reduced discrimination. In line with such findings, Anderson and colleagues (2003) correlated how the frequency of native categories in infants' input affects nonnative category perception. In the English language, coronal stops are more frequent than dorsal stops. At 6 months, infants discriminated both contrasts equally well. At 8 months, infants discriminated the nonnative coronal stop contrast significantly worse than the nonnative dorsal stop contrast. Hence, the authors suggest that the order of emergence of native contrast categories, and the corresponding loss of discrimination to nonnative sounds, rely on the frequency and distribution of the categories present in the input. The more frequent a category is in the native language, the stronger the perceptual representations will be, and the more it will act as an attractor of nonnative contrasts. The DRIBBLER (Dimensionally Reduced Item-Based Lexical Recognition) model proposed by Morgan & Roberts (2001) suggests that phonological categories emerge as nexuses of position-specific variation. Perceptually similar items will be projected near one another in space and clusters of exemplars will emerge as categories that attract the less frequent sounds. Morgan's attractor model is compatible with the Native Language Magnet model proposed by (Kuhl, 2000), which proposes that systematic exposure to the most frequent well formed exemplars of phonemes may distort the initial phonetic space, decreasing the perceptual sensitivity in the neighborhood of native prototypes. Furthermore, infants' mapping of the ambient language warps the acoustic dimensions of speech providing a perceptual filter for future sound processing.

1.3.1.4. Induction of new sounds

In contrasts with the results of previous literature supporting the initial discrimination sensitivities, infants also fail to discriminate some contrasts at early stages in development. Eilers et al. (1975, 1977) showed that 1 and 4 month-old infants have difficulties at discriminating the voiced-voiceless alveolar fricatives consonants /sa/-/za/. In line with their results, Polka, Colantonio, & Sundara (2001) showed that for the English /d/-/th/ contrast, neither English nor French infants showed signs of discrimination at 12 months, while English adult participants succeeded to discriminate. The authors suggested that the particular acoustic properties of the /th/ category as well as its phonotactic properties could account for the observed delay in sound acquisition. Sato et al. (2012) demonstrated that single vs. geminate obstruent and vowel duration are not acquired by Japanese infants until 9.5 months. Similarly, Narayan et al. (2010) found that neither the infants born in English nor Filipino linguistic environments showed initial signs of discrimination of nasal place consonants at 4 and 6 months. Filipino infants showed later discrimination of such contrasts but only at the ages of 10 to 12 months. Their results suggested that for contrasts which are relatively less salient, and that are not discriminable by infants' initial perceptual biases, continued exposure is needed in order to facilitate discrimination.

1.3.2. The role of biology

The perceptual attunement to the specific characteristics of the environment and the decline of discrimination to stimuli that are not present in the input, has not solely observed in phoneme perception, but it has also been reported in other domains. In the auditory (Villers-Sidani & Chang, 2007; Villers-Sidani, Simpson, & Lu, 2008) and visual domains for mammals and humans (Bavelier & Davidson, 2013; Hensch, 2005), in face recognition (Anzures, Quinn, Pascalis, Slater, & Lee, 2010; Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly, Quinn, Slater, & Lee, 2007; Maurer & Werker, 2014; Scott, Pascalis, & Nelson, 2007), in music perception (Hannon & Johnson, 2005), in lexical tones (Mattock, Molnar, Polka, & Burnham, 2008), in intersensory speech perception (Lewkowicz, Leo, & Simion, 2010; Pons, Lewkowicz, Soto-Faraco, & Sebastián-Gallés, 2009), in visual language discrimination (Oyama, 1979; Sebastián-Gallés, Albareda-Castellot, Weikum, &

Werker, 2012; Weikum et al., 2007) and in hand gestures used in sign languages (Baker, Idsardi, Golinkoff, & Petitto, 2005).

Regarding the extension of the perceptual reorganization phenomenon, Scott et al. (2007) claimed that perceptual attunement is a domain-general phenomenon, driven by the neural development coincident with infants' perceptual changes. According to the authors, the synaptic pruning of neural connections in the brain during the first year of life will result into perceptual narrowing entrenched across domains. Hence, the remaining connections would configure the neural basis for the adult perceptual system.

Regarding the timing of the attunement process, some authors have suggested that the narrowing occurs during a very specific time window, within a sensitive critical period, involving gradual shifts in sensitivity to environmental input outside of which learning is still possible although extremely hard (Knudsen, 2004; Maurer & Werker, 2014; J. F. Werker & Hensch, 2014).

In line with the previous assumption, a study conducted by Pena and colleagues (2012) showed that preterm infants, who have 3 additional months of exposure to language in comparison to their full term peers, only lose discrimination to nonnative phonetic contrasts at 15 months, that is, when they match the maturational age of 12 month-old full term infants. Hence, additional exposure to language does not accelerate the process of narrowing in preterm infants since they only lose discrimination to nonnative contrasts when the maturation of their perceptual system reaches the equivalent of full term 12 month-old infants.

Other studies also explained the impact of pharmacology on perceptual reorganization. Vetencourt et al. (2008, 2011) showed that the antidepressant fluoxetine restores plasticity in the adult rats visual cortex. (Simpson & Kelly, 2011) showed that exposure to SRI (serotonin reuptake inhibitor) in rodents during gestation disrupted their fetuses' auditory map formation. Crucially, Gervain et al. (2013) demonstrated that valproate reopens the critical-period for learning absolute pitch in human adults. Hence, neural plasticity of the visual and auditory systems can be influenced by drug treatments in both rodents and humans.

Weikum et al. (2012) tested the effects of SRI on perceptual development by comparing the discrimination abilities of infants exposed to three different gestational conditions: mothers diagnosed with depression treated with SRI during pregnancy, depressed mothers without treatment and control mothers without depression. Infants were tested in utero with a consonant and vowel discrimination task and at 6 and 10 months with a consonant discrimination and with a visual language task. Infants in the control group performed as expected, with vowel but not consonant discrimination in utero, discrimination of consonants and visual languages at 6 months and a decline of discrimination at 10 months in both tasks. SRI-exposed infants showed discrimination of both vowels and consonants in utero, but a lack of discrimination at 6 and 10 months, both signs of initial enhanced discrimination coupled with posterior accelerated development. Infants of depressed mothers without treatment showed the opposite pattern. As the control group, they discriminated only vowels in utero, but showed unreliable discrimination of consonants at 6 months, with a tendency towards a familiarity effect. Only at 10 months they showed robust discrimination.

We can access additional information about sensitive learning periods by studying the development of infants who are born deaf and early in development have hearing aids or cochlear implants. Studies suggest that, in the absence of initial stimulation, their plasticity period may also remain open for a longer period than in hearing infants, with close to full recovery seen up to 3 years of age (Faulkner & Pisoni, 2013; Kral & Sharma, 2012).

Additionally, diet can also change infants' phonetic discrimination responses. Breast-fed infants of vegetarian mothers continue discriminating the nonnative dental retroflex contrast after 10 months of age (Elias & Innis, 2001), and infants fed with soy milk show increased discrimination and delayed neural latencies at discrimination of consonants at 6 months (Pivik, Andres, & Badger, 2012).

Hence, gestational age, exposure to pharmacological treatments, infants’ diet and initial deprivation of linguistic input are biological factors that alter the critical period in phoneme acquisition.

Together, these results confirm that both experience and also biological factors are at play in the process of perceptual reorganization.

1.4. The impact of phonetic perception in language learning

1.4.1. Language comprehension

Numerous studies have posited that the patterns of phonetic discrimination in infants correlate with later word comprehension, vocabulary growth, and sentence complexity. The following studies explored such correlations by comparing behavioral and ERP tasks with MacArthur Communicative Development Inventory (CDI) scores. According to the PRIMIR model (Curtin, Byers-Heinlein, & Werker, 2011; Werker & Curtin, 2005) vocabulary size is not only a consequence of phonetic learning, rather, it also interacts with abstract phonological representations to guide word learning.

Tsao et al. (2004) tested 6-month-old infants' vowel discrimination in a longitudinal study. Infants' discrimination abilities at 6 months predicted their language perception and production skills at 13, 16 and 24 months of age. Conboy et al. (2005) showed that at 11 months, infants' preference for their native contrasts in comparison to nonnative contrasts, correlated with vocabulary comprehension at the same age. Better native perception of consonants predicts advanced language skills while better foreign contrasts perception predicts slower language growth. Kuhl et al. (2005) showed that better discrimination of native sounds at 7 months predicts a higher number of word productions at 18 months and also correlates with word length means and sentence complexity at 24 months. In contrast, better discrimination of nonnative sounds at 7 months predicts worse word production at 18 and 24 months and lower scores at sentence complexity at 24 months.

Also, Rivera-Gaxiola and colleagues (2005) found that infants electrophysiological responses to native sounds increased between 6 and 12 months. Furthermore, their specific neural responses predicted differences in the effects. At 11 months of age, responding to the foreign contrast at the P150–250 as opposed to the N250–550 level, correlated with an increase in infants' vocabulary spurt between 18 and 30 months.

1.4.2. Word recognition

Phonetic acquisition is crucial for infants to acquire the words of their language. They need to become accurate at perceiving the sounds in each word label in order to be able to differentiate similar sounding speech concatenations.

Also, many mechanisms are at play in the process of word learning, and hence they are dependent on phoneme perception as well. In order to learn their first words, infants need to extract the relevant information in the speech stream, link it to the correct referent and store it in memory. Contrary to previous evidence provided by the CDI inventories, infants know the meaning of many common nouns already by 6 months (Bergelson & Swingley, 2012). At the same age, prosody guides word learning even when the label is presented within a continuous speech stream and in the context of a complex visual scene (Shukla, White, & Aslin, 2011). They also store in memory high frequent words in their input from 8 months of age (Johnson & Jusczyk, 1997).

Saffran and colleagues (1996) showed that eight month-old infants compute the statistical probabilities between syllables to segment and extract words from fluent speech from 8 months. Graf Estes and colleagues (2007) exposed 17 month-old infants to the same type of word segmentation task, although in this study an object label learning task immediately followed. Only infants who were tested with words from the segmentation task learned the label. Infants who were presented with part-words of the familiarized stream did not learn the labels.

At 8 months infants are also able to extract and generalize rules from a continuous speech stream (Marcus, 1999). Furthermore, they rely phonetic information to extract linguistic information from their input. Adults (Bonatti, Pen, Nespor, & Mehler, 2005; Jacques Mehler, 2006) and toddlers (Thierry Nazzi, 2005) rely more on consonants than on vowels to identify words from a continuous artificial stream. However, adults use vowels to extract structure generalization (Toro, Nespor, Mehler, & Bonatti, 2008). Such distinct functions for vowels and consonants (Hochmann et al., 2011; Pons & Toro, 2010) are already at use by 12 months, suggesting that infants exploit consonants and vowels as different sources of linguistic information. Therefore, the perception of both vowels and consonants is crucial to acquire words and grammar.

Interestingly, perceptual reorganization occurs earlier for most vowels than in does for consonants, but if word extraction relies on consonant information, the phonetic representation of consonants might be of crucial relevance for vocabulary learning.

However, it is a mystery how infants can map words to meaning when their process of acquisition of phonemes is still ongoing and, therefore, they are not yet good perceivers of the native categories in their input. Previous studies have addressed the question with word-object labeling tasks, to reveal to what extent phonetic representation contributes to the process of acquisition of words.

1.4.3. Mapping words to objects

From the first year of life, infants associate labels to objects if labels are phonetically dissimilar, as in the case of 'lif' and 'neem'. Nonetheless, when they are presented with minimal pairs, that is, with labels which only differ in their onset consonant, such as, 'bi' vs 'di', 'bin' vs 'din', 'bin' vs 'pin', and 'bin' vs 'din' (Pater, Stager, & Werker, 2004; Stager & Werker, 1997). They only succeed at using close phonetic distinctions at 18 months (Werker, Fennell, Corcoran, & Stager, 2002). However, if they are presented words in a task that allows infants to understand the aim of the task, either with a referential training (Namy & Waxman, 2000), with sentence frames rather than in isolation (Fennell & Waxman, 2010), or with a visual choice paradigm to ask them to look for the right object (Yoshida, Fennell, Swingley, & Werker, 2009) they succeed at 14 months. Hence, referential context to the labeling task enables infants to associate words and objects. May & Werker (2014) showed that 14-month-old infants succeed in mapping nonnative Click words to objects in the referential Switch task. In contrast, infants at 20 months with high vocabulary size did not succeed at the task, suggesting that their familiarity with the word forms of their language is linked to the phonological structure of novel forms when learning new labels. In the lack of referential cues, none of the groups succeeded at the task. The same results were found when Mandarin lexical tones are used instead of Clicks. Recent results by Hay, Graf Estes, Wang, & Saffran (2015) indicate that 14-month-olds remain flexible regarding what sounds make meaningful distinctions between words since they are able to map objects to nonnative tonal labels. From 19 months, infants no longer interpret such variations as lexically relevant, although they continue to be sensitive to variations in pitch contour when there is not a mapping task.

In sum, the words infants learn do depend on the phonetic contrasts they can perceive and on their interpretation of the phonological relevance of such contrasts in their native language.

1.5. The case of bilinguals

1.5.1. Bilingualism: only a measure of linguistic experience?

According to The Encyclopedia of Bilingualism and Bilingual Education published in 1998, around two thirds of the world's population are bilingual. According to the reports of the European Commission from 2006, more than 56% of the citizens in the European Union are bilingual. Only in the United States, the amount of people who speaks more than one language has been doubled between 1980 and 2007 from a 11% to a 20% of the population (U.S. Census Bureau, 2007). Despite the increasing population of bilinguals around the world, research in the field of language acquisition has been mainly focused in the study of single language users, using the data of monolinguals as a baseline for comparisons with groups that are exposed to other linguistic experiences. However, studies tapping onto the acquisition of language in bilinguals are not only relevant for reporting how differences in the infants' linguistic experience may influence their development but, furthermore, together with the results of studies with monolinguals, they provide a more representative view of how infants in the world acquire language.

1.5.2. Similarities between monolingual and bilingual language skills

As it has already been reported in the case of newborns in monolingual environments (Mehler et al., 1988), at birth, infants who have been gestated in bilingual environments can also discriminate the difference between their two native languages as long as they are rhythmically distinct (Byers-Heinlein, Burns, & Werker, 2010). Whenever their languages belong to the same rhythmic category they are not able to discriminate between the two until the age of 4.5 months (Bosch & Sebastián-Gallés, 1997). Bilingual infants show evidence of segmentation of words at the same age as it has been established for monolinguals, that is, around 7.5 months of age (Jusczyk & Aslin, 1995). Despite the additional challenges regarding language learning in bilingual environments, bilingual infants acquire their first words at around the same ages as monolinguals (Oller & Eilers, 1997; Pearson, Fernandez, & Oller, 1993; Petitto & Katerelos, 2001). Moreover, their total vocabulary sizes, when accounting for the words in both of their languages, are comparable (Hoff, Core, & Place, 2012; Pearson et al., 1993; Petitto & Katerelos, 2001), except for the case of mixing environments, in which case their total vocabulary sizes is compromised (Byers-Heinlein, 2013).

1.5.3. Additional challenges for language acquisition in bilingual contexts

Bilingual infants have to reach the same milestones as monolingual infants in a more challenging learning environment. They have to sort and parse the linguistic information in their environment simultaneously for two languages, in a context of increased input variation and with less exposure to each language (Byers-Heinlein & Fennell, 2014).

Bilingual infants seem to attune their perception to each of their languages separately (Bosch & Sebastián-Gallés, 1997; Curtin et al., 2011; Werker, Yeung, & Yoshida, 2012). However, in bilingual environments the two languages are not always presented in a neat differentiated way but, instead, they are often intermixed. In the same context, bilingual adults may simultaneously alternate between the two languages, even within the same sentence (Byers-Heinlein, 2013). For instance, regarding the acquisition of grammar, Gervain & Werker (2013) reported that 7 month-old bilingual infants who are exposed to one OV and one VO language, use prosody to discern the frequent word order for both of their two languages. At the same age, monolinguals' word order preference may not be reversed throughout prosody. Instead, they only rely on word frequency as a cue for order. The authors suggest that prosody may be at use in bilinguals as a bootstrapping strategy for grammar structures.

Furthermore, the bilingual input is often less precise than the monolingual input. Bosch & Ramon-casas (2011) found that bilingual mothers are less precise than monolingual mothers in their productions of native sounds. Catalan-Spanish bilingual mothers make frequent vowel category errors at producing words that contain the /e/-/ɛ/ contrast, which is present in the Catalan but not in the Spanish phonological repertoire, despite the acoustic differences of their /e/ utterances is similar to the productions of Catalan monolingual mothers. Their results suggest that the bilingual input of Catalan-Spanish bilingual infants is noisier. Despite of the common overall time that bilingual and monolingual infants are exposed to language, bilingual infants have less relative exposure to each of their two languages (Curtin et al., 2011; Hoff et al., 2012; Kuhl et al., 2008; Werker & Byers-Heinlein, 2008; Werker, 2012). Therefore, bilingualism offers a suitable case for exploring how the input frequency influences language learning.

1.5.4. The final stage: categorical perception in bilingual adults

Studies testing adults on the dental-retroflex contrast (Burfin et al., 2014) and studies testing toddlers on Salish contrasts (Von Holzen & Mani, 2012) show that monolingual and bilingual adults encounter similar difficulties at discriminating nonnative sounds.

However, the differences in the early input of bilingual populations affect their later language abilities. Bilingual adults who learned both languages early in life sometimes show patterns of speech processing consistent with monolinguals of their dominant language but are less proficient than their monolingual peers in their non-dominant language (Cutler, Mehler, Norris, & Segui, 1989; Dupoux, Peperkamp, & Sebastián-Gallés, 2010; Dupoux & Sebastián-Gallés, 2008). Also, they show difficulties at discriminating and producing certain contrasts of their native languages (M Sundara & Polka, 2008; Megha Sundara, Polka, & Genesee, 2006). Studies testing Catalan-Spanish bilinguals on discrimination of the sounds of their two languages show that predominant exposure to either the Catalan or Spanish phonetic repertoire in their first years of life shapes their perceptual system. Catalan has more vowel (8 as opposed to 5) and consonant contrasts (25 as opposed to 19) than Spanish. Moreover, some of the additional contrasts in the Catalan phonological repertoire are assimilated as exemplars of the same phonetic category by Spanish speakers. That is, for those contrasts, the differences between the phonological repertoires in the linguistic input result into perceptual differences between users of each language, Spanish speakers perceive unimodal frequency distributions whereas Catalan speakers perceive bimodal frequency distributions. More specifically, within the phonological space of the Spanish phoneme /e/, two different contrasts, /e/ and /ɛ/, are represented in Catalan. The same phenomenon occurs for the vowels /o/-/Ɔ/ and for the voiced-unvoiced fricative consonants /s/-/z/ and /ʃ/-/ʒ/, although in the last couple of contrasts the closer equivalence in the Spanish phonology space shall depend on phonotactic constraints. Hence, categorical perception is different for the speakers of each of the two languages.

Many experiments have studied such differences in perception with Catalan-Spanish bilingual populations. Ratings on vowel proto-typicality in early Catalan-Spanish bilinguals vary according to their dominant language (Bosch et al., 2000; Pallier et al., 1997). Even if they are exposed to their second language from 5 years of age, their performance at discriminating vowels that are close to the prototypical values in their dominant language is poorer than for values close to the prototypes in their second language (Bosch et al., 2000). When Spanish-dominant bilingual speakers, who have been exposed to Catalan from 3 years of age, are presented with a gating task, they perform systematically worse than Catalan-dominant bilinguals at identifying /e/-/ɛ/ and /o/-/Ɔ/ vowel contrasts and the consonant contrasts /ʃ/-/ʒ/ (Navarra & Soto-Faraco, 2007; Sebastián-Gallés & Soto-Faraco, 1999).

Furthermore, Pallier et al. (2001) showed that the perceptual differences resulting from language dominance have an impact on lexical access, since Spanish monolinguals treated minimal pairs with Catalan phonemes as homophones.

Since, according to the previously mentioned studies, the experience during the first years of life is crucial for later language perception, further studies were conducted to determine when and how linguistic experience shapes infants' perceptual systems.

1.5.5. Perceptual reorganization in bilingual infants

Previous studies have demonstrated that the bilingual experience can alter the process of perceptual narrowing in the domain of visual speech perception. Weikum et al. (2007) showed that until 6 months, when infants are presented with muted videos of female faces speaking, both monolingual and bilingual infants show increased interest if the speaker switches in language, suggesting that they are able to discriminate the language change visually. In contrast, at 8 months only bilinguals maintain sensitivity to such visual language switch, whereas at that age monolingual infants show the typical decline in sensitivity previously described. Moreover, Sebastian-Galles et al. (2012) replicated their results testing Catalan-Spanish monolingual and bilingual infants. Importantly, the stimuli presented to Catalan-Spanish bilingual infants was the French-English speaking faces used in the previous study by Weikum and colleagues (2007). Catalan-Spanish bilinguals revealed that discrimination at 8 months did not depend on infants' experience with either of the two experimental languages but, instead, authors claimed that bilingualism has an impact on infants' attentional system.

Similarly, Palmer et al. (2012) showed that, at 4 months, English speech-sign learners are able to discriminate language relevant hand shape distinctions from a different sign language, American Sign Language (ASL). However, by 14 months they cease to discriminate ASL. In contrast, bilingual English-ASL speech-sign learners maintain sensitivity until 15 months, despite their more reduced exposure to each of their sign languages.

Nonetheless, studies about speech phonetic acquisition in bilingual infants offer a more complex scenario regarding the perceptual reorganization of sounds.

1.5.5.1. Maintenance

Anderson et al. (2003) concluded that, in monolingual populations, the amount of exposure to their native contrasts affects the timing of loss of discrimination to nonnative contrasts. Consequently, since bilingual infants have less exposure to the sounds of each of their two languages, it is possible that bilingualism alters the process of perceptual reorganization. Also, according to Maye et al. (2002), unimodal frequency distributions have the effect of reducing discrimination, while bimodal distributions have the converse effect. The increased difficulty of Catalan-Spanish early bilingual adults in processing the native bimodal distributions of Catalan that are unimodal in Spanish suggests that the differences in the languages phonological repertoires may be at play in the process of perceptual reorganization bilingual infants.

Bosch & Sebastián-Gallés (2003a) conducted a series of studies in which Catalan and Spanish monolingual infants and Spanish-Catalan bilingual infants were tested on native /e/-/ɛ/ vowel contrasts throughout development. All groups discriminated at 4 months. At 8 and 12 months, only Catalan monolingual infants maintained sensitivity to their native contrast whereas Spanish monolinguals no longer discriminated. These results report both a maintenance in the presence of exposure to the sounds and loss of discriminability in the absence of exposure in the case of monolingual populations. Interestingly, bilingual infants failed at discriminating their less frequent /e/-/ɛ/ contrasts at 8 months, and again successfully discriminated the contrast at 12 months (Bosch & Sebastián-Gallés, 2003a). Similar U-shaped results were reported for some native contrasts in both languages /o/-/u/ but not for others like /e/-/u/, suggesting that bilinguals' lack of discrimination at 8 months could possibly rely on the acoustic closeness of the target phonemes. Albareda-Castellot, Pons, & Sebastián-Gallés, 2011) addressed the same question testing bilingual infants with an anticipatory eye-movement paradigm and showed that infants successfully discriminated /e/-/ɛ/ contrasts at 8 months. Sundara & Scutellaro (2011) reported the same /e/-/ɛ/ discrimination results in 8-month-old English-Spanish bilinguals. Hence, these more recent results suggest that the initial U-shape pattern observed in 8 month-old bilinguals depended of how bilinguals' perform at the specific task rather than on their discrimination capacities. Such results are also valid in the case of consonants (Bosch & Sebastián-Gallés, 2003b; Sundara, Polka, & Molnar, 2008). At 10-to-12 months, French–English bilingual infants maintain both English-specific and French-specific /p/–/b/ distinctions, while monolingual English learners maintain only the English-specific distinction at this age (Burns, Yoshida, Hill, & Werker, 2007).

Therefore, from these set of results with bilingual infants, and in line with the results obtained with bilingual sign-language infants (Palmer et al., 2012), we can conclude that discrimination of native sounds is maintained as long as there is continued language exposure, and regardless of the amount of language input. Coupling these results with the data obtained by Peña et al. (2012), we observe that perceptual attunement is not easily permeable to the differences in the linguistic input.

1.5.5.2. Enhancement of initial sensitivities

More recent studies (Liu & Kager, 2015) suggest that in the case of perception of vowels contrasts that infants are not able to discriminate at birth, bilingual infants show discrimination at 8 months whereas monolingual infants do not discriminate such difference until 12 months. The authors explain such results as a perceptual lead in the case of bilinguals, which could be due to linguistic or cognitive advantages. However, more results testing similar contrasts would be needed in order to confirm the generalization of their results.

1.5.5.3. Learning by forgetting: loss of sensitivity to nonnative contrasts

Unlike the case of maintenance of initial sensitivities, comparing monolingual and bilingual infants in perception of contrasts that are nonnative in both of their languages can help to shed light onto the effects of bilingualism when specific input factors are factored out.

Although many studies have reported the process of perceptual narrowing of consonants in monolingual infants, so far, only brain imaging data has been provided for bilingual infants.

Petitto et al. (2012) presented infants at 4-6 months and at 10-12 months with the dental-retroflex consonant contrast used in the classic behavioral studies by (Werker et al., 1981; Werker & Tees, 1984a, 1984b). Their results showed that bilingual infants' still show neural sensitivity to nonnative retroflex contrasts between 10 and 12 months, when monolingual infants no longer make such distinctions. Crucially, such prolonged period of sensitivity in bilinguals could not be due to sound exposure since the retroflex distinctions are not present in either of their two languages. Hence, authors posited that the bilingual experience enhances the period of neural sensitivity of bilinguals and constitutes an advantage as opposed to a delay in language development. Other authors have suggested that the offset of the critical period might occur later in bilinguals due to the increased variability in the bilingual input (Werker & Hensch, 2015). However, up to date, the existing literature has not reported how the neural data in bilinguals correlates of with their behavior, when perceptual narrowing finishes in bilingual infants, and whether bilingual exposure impacts in a quantitative or in a qualitative manner.

1.5.6. Mapping words to objects and word recognition

Studies testing bilingual infants on object mapping studies suggested that experience alters discrimination of minimal pairs.

Studies regarding minimal pairs discrimination initially suggested that monolingual infants succeed at discriminating bih-dih at 17 months (Werker et al., 2002) while neither English-French nor Chinese-English bilingual infants do not succeed until 20 months when presented with the same task (Fennell, Byers-Heinlein, & Werker, 2007) .However, bilingual infants succeed at learning the minimal pairs at the same age than monolingual infants, at 17 months, if stimuli are produced by the bilingual speaker (Mattock, Polka, Rvachew, & Krehm, 2010) and if words are embedded in naming phrases (Fennell & Byers-Heinlein, 2014).

Recent results by Hay, Graph Estes & Saffran (2015) indicate that 14-month-olds remain flexible regarding what sounds make meaningful distinctions between words since they are able to map objects to nonnative tonal labels. From 19 months, infants no longer interpret such variations as lexically relevant, although they continue to be sensitive to variations in pitch contour when there is not a mapping task. However, in the case of bilingual infants, their period for mapping objects to tonal labels remains open until 22 months of age (Graf Estes & Hay, 2015).

As for word recognition, when bilingual toddlers and children between 3 to 8 years of age are presented with minimal pairs, they can discriminate the difference between words containing /e/-/ɛ/ only if they are Catalan-dominant bilinguals although they do not show discrimination if they are raised in Spanish-dominant bilingual environments (Ramon-Casas, Swingley, Sebastián-Gallés, & Bosch, 2009). Conboy & Mills (2006) used event related potentials to test lexical knowledge in 19 and 22 month-old English-Spanish bilingual infants. Their findings reveal a more focalized response to known words in the dominant than in the less-often-used language, reflecting more efficient, more automatized processing in that language.

1.5.7. Cognitive and attentional abilities in bilinguals

The differences between monolingual and bilingual infants go beyond the differences in the language domain. Unlike their monolingual peers, 7 month-old bilingual infants can learn two different sets of grammar rules as opposed to only one (Kovács & Mehler, 2009). Importantly, in this particular study bilinguals were able to inhibit their first conditioned response in order to learn a new set of rules, whereas monolinguals could not change their responses after the rule switch in the task. The authors claimed that bilingualism improves domain-general abilities like their executive functions, and that such benefits serve as a strategy for keeping separate linguistic representations for each of their two languages.

Singh et al. (2014) compared 6-month-old monolingual and bilingual infants' performance during a non-linguistic Infant Visual Habituation task. They showed that, in comparison with monolingual infants, bilingual infants showed a greater attentional decrement from the beginning to the end of the study, with steeper slopes of habituation. Their results were interpreted as a cognitive processing/attentional advantage in bilinguals, in line with the previously described interpretations by Sebastián-Gallés et al. (2012) in their visual speech reorganization studies. Therefore, both attentional and cognitive skills in bilingual infants could potentially be at play in the process of phoneme acquisition and provide different perceptual and learning strategies.

1.6. Field framework and current research

In conclusion, bilingual exposure impacts later language skills, sometimes with a distinct outcome than monolingual exposure does.

As previously discussed, perception and word recognition in toddlers and in early bilingual adults depends on the amount of exposure to each of their two languages (Bosch et al., 2000; Conboy & Mills, 2006; Ramon-Casas et al., 2009; Sebastián-Gallés & Soto-Faraco, 1999). However, the impact of experience in the process of phoneme acquisition is not so clear.

1.6.1. Equal performance implies equal processes?

Bilingual infants keep the pace of their monolingual peers and maintain the initial sensitivity to their native sounds (Bosch & Sebastián-Gallés 2003b; Burns et al., 2007; Sundara et al., 2008; Albareda-Castellot et al., 2011). Nevertheless, such continued exposure is not equivalent to the exposure of monolinguals, since it is relatively limited in frequency due to the presence of two languages. Therefore, the results from native contrast discrimination in bilingual infants could be leading to two different interpretations. First, that minimal exposure to sounds, together with the right stage of biological maturation, may be enough to maintain contrast discrimination. Second, and alternatively, bilingual infants may be more efficient at processing information than monolinguals, since they achieve the same milestone with less exposure to their sounds.

In this second case, such efficiency could be caused by different possible factors, either by acoustic or perceptual additional sensitivity or either by attentional enhancement derived from the bilingual experience.

We may be able to disentangle whether exposure or a bilingual advantage account for the equal timing in the maintenance of native sounds' sensitivity by comparing monolingual and bilingual infants on nonnative sound discrimination -as opposed to comparing them on native sound discrimination-. That is, by exploring bilinguals' discrimination of nonnative sounds we could factor out the role of exposure to native sounds as a sufficient factor for their acquisition of native phonemes.

1.6.2. Studying nonnative sound discrimination to factor out the effects of phoneme exposure

Studies with electrophysiological data (Cheour et al., 1998; Rivera-Gaxiola et al., 2005) and meta-analysis performed on vowel acquisition studies (Tsuji et al., 2014) describe an inverse correlation between infants' timing of acquisition of native sound categories and the decay in discrimination of nonnative contrasts. Furthermore, Anderson et al. (2003) concluded that, in monolingual populations, the amount of exposure of different native contrasts affects the timing of loss of discrimination to their corresponding nonnative contrasts. The brain imaging study by Petitto et al. (2012)

showing that bilingual infants remain sensitive to nonnative consonant distinctions at a stage when monolingual infants have already lost sensitivity, suggests that there might be a mismatch between native and nonnative consonant perception. Importantly, in their study they tested bilingual infants exposed to English and another language, which varied across participants. Hence, and following the findings by Anderson et al. (2003), their native-nonnative timing mismatch in bilingual infants could be, rather than an effect of bilingualism, an effect of a different frequency of occurrence of the native sound /t/ in the bilingual input than in the monolingual input. Therefore, by testing bilingual infants on the discrimination of similarly frequent versus equally non-frequent foreign contrast in both of their languages, we might be able to separate the effects of bilingualism from the effects of frequency of occurrence of sounds in the native language. Catalan and Spanish monolingual and bilingual infants provide the case in which we can remove the variable frequency of exposure to the native consonants as a factor for narrowing of nonnative consonants in bilinguals. As we will explain in the following paragraphs, we also used the dental-retroflex contrasts to test infants' discrimination abilities. The relative frequency of occurrence of the dental category is quite similar in Spanish and Catalan (Spanish /t/=4.52%, Catalan /t/ =5.17%), and the nonnative retroflex contrast is equally absent in both languages' repertoires. Hence, our Spanish-Catalan bilingual and monolingual groups should be equated on that respect. A second comparative asset of our study was that culture and socio-economic status could also equated between monolingual and bilingual populations.

1.6.3. The relevance of consonants' acquisition

We know that soon after their first birthday infants increase their vocabulary sizes and that precisely at such stage phonetic perception impacts label learning. Therefore, if bilinguals' timing of acquisition of phonemes is expanded, as Petitto and colleagues (2012) suggest, word learning in bilingual infants could potentially be compromised. Especially, in the case of acquisition of consonants. We have mentioned that the role of consonants in detecting possible word candidates in the linguistic stream (Bonatti et al., 2005; Nazzi, 2005; Mehler et al., 2006) is already at play at 12 months (Hochmann et al., 2011). Interestingly, perceptual reorganization occurs earlier for most vowels than it does for consonants, but if word extraction relies on consonant information, the phonetic representation of consonants might be of crucial relevance for vocabulary learning.

1.6.4. Our proposal

If at 12 months the discrimination of nonnative consonants is still a possibility in bilingual infants, then the success at word acquisition in bilinguals would rise additional questions. How can infants map words to meaning when their process of acquisition of consonants is still ongoing? Do they track words on the basis of acoustic perception, as opposed to categorical perception? And if so, what other strategies are at play to compensate for the consequent perceptual ambiguities?

In sum, by examining the process of perceptual reorganization of nonnative consonants in bilingual infants such questions could be answered and we could further understand if the previous results of phoneme discrimination with bilingual infants are a consequence of the restricted frequency of occurrence of sounds (Anderson et al., 2003), of attention (Sebastián-Galles et al. 2012), or of a delay in the offset of the critical period (Werker & Hensch, 2014).

Thus, the framework of the first set of experiments of this dissertation is based on the studies of Werker and Tees (1984a). We know that 6 to 8 month-old English monolingual infants can still discriminate the difference between native and non-native sounds, while at 1 year of age they have already narrowed their phonetic repertoire to their native sounds. Thus, 12 month-old monolinguals are not able to detect the difference between their native dental sound /t/ and the non-native retroflex Hindi contrast /T/. Such lack of discrimination remains until adulthood and it has been demonstrated in several language populations, from English speakers (Golestani & Zatorre, 2009; J. F. Werker et al., 1981) to Catalan-Spanish bilingual speakers (Burfin et al., 2014). Thus, we used the same native versus non-native discrimination stimuli as a predictor to test Catalan-Spanish bilingual infants on perception of nonnative consonants.

Infants who by 12 months of age have already narrowed their perception of sounds to their native constraints -monolingual infants- are not expected to discriminate the difference between the test contrasts /ta/-/Ta/. In contrast, if the phonetic narrowing process has not been finished in bilingual infants, they will be able to detect the change among both test phases, by looking more to the screen when the new non-native retroflex -different from native sound- was presented. In the following chapter we will show the evolution of nonnative sound discrimination in monolingual and bilingual infants and we will frame our findings in the context of the existing literature. In chapter 3, we will present what kind and how much exposure account for the results obtained in the consonant discrimination studies. Finally, in chapter 4, we will show how infants' productions during the discrimination task can provide relevant information to better understand the process of perceptual narrowing.

2. THE DEVELOPMENT OF NONNATIVE CONSONANTS' DISCRIMINATION IN MONOLINGUAL AND BILINGUAL INFANTS

2.1. Experiment 1: Discrimination of non-native consonants at 7 months

In Experiment 1 we tested the prosodic contrast /Ta/-/ta/ with 7 to 8 month-old monolingual and bilingual infants to explore whether early discrimination was independent of the kind of language exposure. On the basis of the existing literature at the moment when this experiment was conducted (2010), we were unable to make strong predictions on whether the young bilingual infants would succeed or fail to discriminate the difference among both contrasts. If at 7 to 8 months bilinguals infants are able to discriminate as monolingual infants do, we could then conclude that bilingualism does not alter the onset of the phonetic narrowing for nonnative phonemes. Alternatively, if at this stage the discrimination pattern of bilinguals differs from that of monolinguals, that is, if bilinguals have already ceased to discriminate the difference between the two contrasts, we would then conclude that bilingualism accelerates the phonetic narrowing process by at least 3 months with respect to monolinguals. In order to test both hypothesis we tested 7 month-old monolingual and bilingual infants following an infant habituation procedure.

2.1.1. Methods

2.1.1.1. Participants

Forty-four infants (22 females) from 7;00 to 8;00 months of age (mean age 229 days, range 213 to 240). Twenty-two infants were raised in Catalan or Spanish monolingual environments (C=7, S=15) and 22 were raised in Catalan-Spanish bilingual environments. All infants were full term with no reported health problems and were recruited from the same database as in the previous set of experiments. In each language group, 11 subjects were assigned the Same-Switch condition and 11 subjects were assigned the Switch-Same condition. Before running the experiment, a parental consent was required to be signed and a detailed language questionnaire was administered to establish infants' linguistic background since birth (Bosch & Sebastián-Gallés, 2001). The questionnaire collects information about which languages are addressed to the infants by the adult speakers they interact with. Parental reports include the total number of hours each adult spent with the infant from birth until the experimental date. Once all the speakers information is collected, the total exposure to each language is extracted by summing the number of hours that have been reported for each language across speakers. The percentage of exposure to each language, with respect to their total linguistic exposure, is finally extracted to determine the comparative exposure to each language. The classification of infants into the monolingual or bilingual category was set to a threshold of a 20% of exposure to the non dominant language (L2). Hence, infants for which the exposure to L2 was below the 20% threshold were categorized as monolinguals and infants with an exposure to L2 above the 20% threshold were classified as bilinguals.

An additional 23 monolingual infants were tested but not included in the analysis due to fussiness (4), crying (4), not reaching the habituation criterion within less than 24 trials (3), habituating within the first 6 trials (4), short looking times in the post-test phase (1), parental interference (2), sickness (1), refusing to look to the screen (3), experimenter error (1). Fifteen additional bilingual infants were also excluded from analysis due to crying (5), not reaching the habituation criterion within less than 24 trials (7), habituating within the first 6 trials (1), parental interference (1), South-American Spanish environment (1).

2.1.1.2. Materials

Before the beginning of the habituation and after the end of the test phase, a movie of a spinning waterwheel toy (see Figure 1) with a background sine wave tone was presented as a measure to compare infants engagement between the beginning (pretest) and the end (posttest) of the task. The movies were 12 s long.

The experimental stimuli were multiple exemplars of the phonemes /ta/ and /Ta/ with infant-directed speech intonations, produced by a Hindi native speaker. Eight natural tokens were selected for each phonetic category. In order to minimize acoustic differences across categories, tokens were matched by syllabic duration, pitch and intensity, measured with Praat (Boersma & Weenink, 2005). The sounds were AIFF files, monaural, the sampling frequency was 44100 Hertz, and the encoding was 16 bit big-endian. The main acoustic characteristics of the stimuli are reported in the *Anexxus*. The visual stimulus presented for the duration of all trials across habituation and test was a static image of a black and white checkerboard (Figure 2). Between trials, a video of a yellow looming ball in the center of a black background screen was presented as an attention getter (Figure 3).

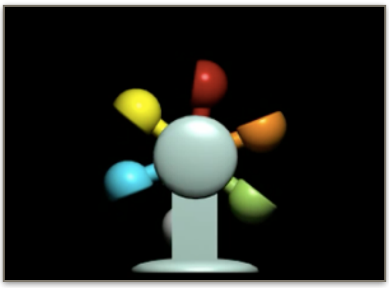

Figure 1. Spinning waterwheel

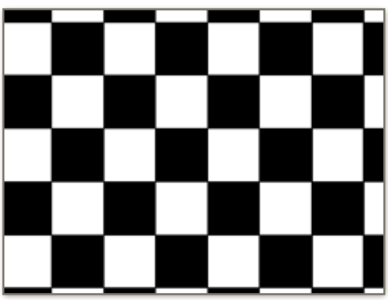

Figure 2. Checkerboard

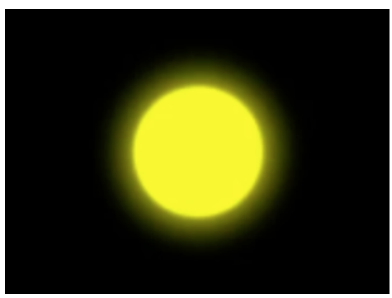

Figure 3. Yellow attractor

The dimly lit recording booth was covered with white curtains, and only one central screen was visible. Infants were seated on their parent's lap at 80cm distance from the central screen. Two speakers located behind the curtains on each side of the monitor played the audio stimuli. The central monitor was a 27" ASUS-VE276N (22 x 64,3 x 44,6 cm), with 1920 x 1080 pixel resolution. A *Sony HDR-HC9E* camera, was located on top of it were surrounded by black cloth, which stretched the width and height of the room. A rear mirror was located on the back corner of the room adjusted with the appropriate angle to reflect the content of the visual stimuli presented in the central screen. Thus, the video recordings of each experimental session also included the visual information presented to the infants. The mirror set-up was aimed at indicating the beginning and the end of each trial, to detect possible experimental or program errors during the session and to provide further accuracy in the off-line coding.

The experiment was run from an *Apple Mac Pro* computer located outside the experimental room, running the open-source software *PsyScope* (http://psy.ck.sissa.it). From this computer, the experimenter controlled the experiment by pressing the mouse button whenever the infant was looking to the screen and by releasing the button whenever the infant looked away from the screen. A second computer *Apple Mac Mini* recorded the full session with the software *iMovie* in order to store the materials for a second coding of the infant gaze behavior performed offline. Its corresponding monitor, a *Philips 26PFL2908H/12* 22", was set to the tv mode option to display time-precise information about infants' behavior.

All the phases of the experiment, including pretest, posttest and habituation, were coded offline with the software PsyCode (http://psy.ck.sissa.it/PsyCode/PsyCode.html). Trials were coded frame-by-frame (1 frame = 40 ms). The software DataDesk was used for posterior data analysis.

2.1.1.3. Procedure

Infants sat on their caretaker's lap facing the screen (Figure 4). To ensure that the infants' looking-behavior was not affected by parental influence, parents wore headphones and listened to classical music during the experiment without beat instruments so the music stream was not audible in the room.

Figure 4. Experimental set-up

We implemented an infant-habituation procedure patterned following the design adopted by Narayan et al., 2010. At the beginning of each trial, the attention getter attracted the infant's attention towards the center of the screen. After the infants looked for 2 consecutive seconds to the center, the experimenter initiated the trial by clicking the mouse when infants fixed their gaze on the attention getter appearing on screen. The trial proceeded then with a fix duration of approximately 12.5 seconds, without further experimenter's interventions. The experimenter recorded infants' looking times by pressing the mouse for as long as infants looked to the screen. The experiment consisted of 4 phases, pretest, habituation, test and and posttest (see Figure 5).

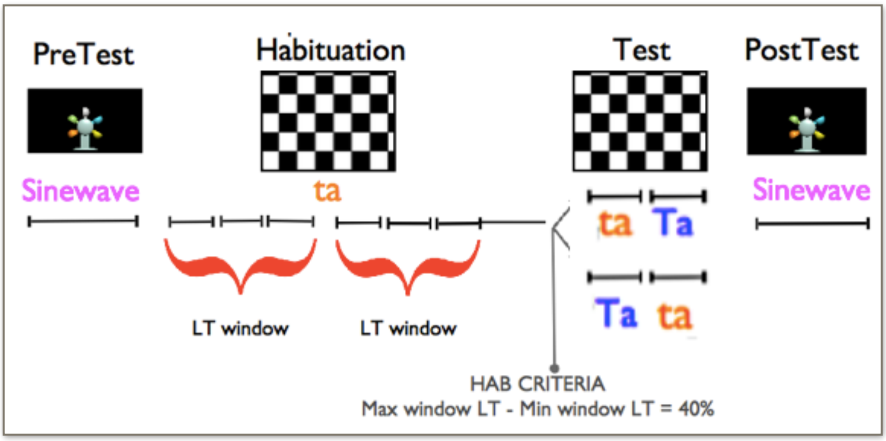

Figure 5. Procedure schema

<u>Pretest</u>: A waterwheel video was played at the center of the screen while a sinewave sound was presented. The total duration of the trial was fixed 12s.

<u>Habituation:</u> After the pretest phase the habituation begun. Each habituation trial consisted of 8 tokens of the native syllable /ta/, presented in a random order, while a black-and-white checkerboard was presented on screen. An attention getter was presented between trials. Looking times were computed over blocks of three consecutive trials and the mean of each independent block was recorded. The criterion of habituation was set to a decrement of 40% of the longest block mean, and therefore could only occur after trial number 6. The minimum length of the habituation phase was set to 9 trials and the maximum to 24 trials. Infants who habituated before Block 3 or after Block 8 were excluded from the analysis.

Test Phase: After infants reached habituation, two test trials were presented. The Same trial, with eight /ta/ syllables containing the dental sound. And the Switch trial, with eight /Ta/ syllables containing the retroflex sound. The order of presentation of the syllables was randomized. The order of presentation of the two test trials was counterbalanced across participants for each language group. The visual stimuli were exactly the same as in habituation.

Posttest: The same stimuli presented during the pretest phase were played again as a measure to compare infants engagement between the beginning (pretest) and the end (posttest) of the task.

2.1.2. Results

A 2 (test trial type: pretest vs. posttest) x 2 (language group: monolingual vs bilingual environment) mixed design repeated-measures ANOVA with participants as random factor nested within language group was conducted in order to determine whether infants reduced attention during experiments (insofar as looking time to the central attractor measures it), and whether a potential reduction in looking time between the pretest and posttest phase was equally affecting both language groups. There were no significant differences of language or test trial type nor any interaction ($M_{Mon*PreTest}$ = 11.64 s, SE=0.19, $M_{Mon*PostTest}$ = 11.93 s, SE=0.09; $M_{Bil*PreTest}$ = 11.79 s, SE=0.19, $M_{Bil*PostTest}$ = 12.02 s, SE=0.09, $F(1, 42)=0.04$, p=0.83), showing that infants in both groups did not reduce interest in a noticeable way from the beginning to the end of the experiment.

To address our main question of whether both language groups could discriminate the difference between a native and a nonnative contrast at 7 months, we conducted a 2 (test trial type: Same vs. Switch) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. A main effect of test trial type emerged, (M_{Same} = 4.79 s, SE=0.31, M_{Switch} = 5.73 s, SE=3.21, $F(1, 42)=4.41$, p=0.039 (see Figure 6). There was no effect of language group, $M_{Monolinguals}$ = 5.2 s, SE=3.33, $M_{Bilinguals}$ = 5.31 s, SE=3.09, $F(1, 42)=0.05$, p=0.83, nor any significant interaction between language and test trial, $M_{Mon*Same}$ = 4.56 s, SE=4.77, $M_{Mon*Switch}$ = 5.85 s, SE=4.31, $M_{Bil*Same}$ = 5.01 s, SE=3.86, $M_{Bil*Switch}$ = 5.60 s, SE=4.84; $F(1, 42)=0.62$, p=0.42). That is, as depicted in Figure 6, both language groups showed dishabituation to the nonnative contrast by looking significantly longer to the screen during the Switch test trials than to the Same trials.

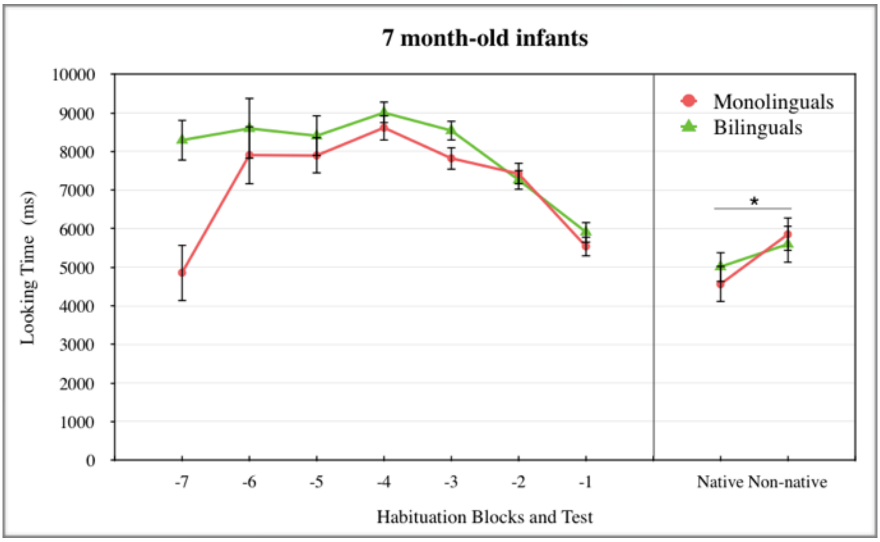

Figure 6. Mean looking times (in milliseconds) across habituation blocks and test trials in monolinguals and bilinguals at 7 months. Habituation blocks are numbered starting from the last habituation block to the first (backwards). Error bars represent standard errors.

Although we did not observe differences between language groups, the means suggested a reduced pattern of discrimination responses in bilinguals. Scheffe post-hoc comparisons were examined regardless the lack of differences between groups to assess the size of the discrimination effects. The bilingual group showed a weaker discrimination response towards the Switch trials (M=-5.86, SE=0.47, p=0.22) than the monolingual group (M=-1.29, SE=0.47, p=0.009). Since the reduced pattern of discrimination responses of bilinguals could represent a possible precursor of loss of sensitivity to nonnative contrasts, we then studied whether finer relations between the amount of exposure and discrimination could be observed in such group. We explore the developmental trajectory of discrimination in the period from 7 to 8 months with a regression, entering infants' age (days since birth) as a predictor for discrimination scores (difference in looking proportions between Same and Switch trials). The regression revealed no effect of infants' age on discrimination (Figure 7), although younger participants tended to show better discrimination of the non-native contrast with respect to older participants (R^2=14.4%, $F(1, 20)=2.35$, p=.08).

We also ran an ANOVA by splitting age at its median, in order to compare the discrimination responses of older subjects against the younger subjects between 7 and 8 months of age. Again, there was a strong but not significant trend suggesting that younger bilingual infants looked longer than older infants to the retroflex trials ($F(1, 20)=2.67$, p=.07).

Since there were two different conditions of order of presentation of the test trials (Same-Switch and Switch-Same), which imply differences in the timing of presentation of both trial types, we also analyzed whether there were effects of order between language groups. We conducted a 2 (order condition: Same-Switch and Switch-Same) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. As represented in Figure 8, there was no interaction of order condition and language group ($M_{Mon*SameSwitch}$ = 4.88 s, SE=0.46, $M_{Mon*SwitchSame}$ = 5.54 s, SE=0.48, $M_{Bil*SameSwitch}$ = 5.03 s, SE=0.51, $M_{Bil*SwitchSame}$ = 5.58 s, SE=0.35; $F(1, 40)=.01$, p=.92).

Separate analysis checked the effects of gender and age, to ensure that there were not additional interactions, and we also explored whether the number of habituation blocks was different between language groups as to determine whether infants showed different patterns of habituation as a function of their linguistic background. We found no effects of these variables.

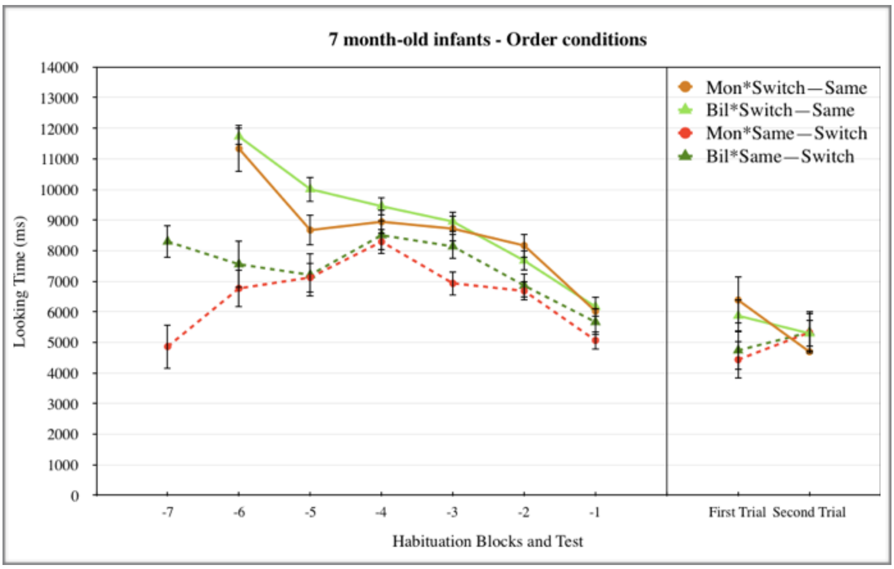

Figure 8. 7-month-old monolingual and bilingual infants' mean looking times (in milliseconds) are depicted by test conditions (Same-Switch and Switch-Same). Habituation blocks are numbered starting from the last habituation block to the first (backwards) and the test phases are presented by order of presentation (first or second). Error bars represent standard errors.

2.1.3. Discussion

From our findings we can extract two main conclusions.

First, our results with Catalan and Spanish monolingual infants confirmed the results of previous studies obtained with English monolingual infants. The finding of a maintenance-related decline in performance on nonnative contrasts has been replicated in a number of studies (Albareda-Castellot et al., 2011; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Laura Bosch & Sebastian-Galles, 2003; Burns, Werker, & McVie, 2003; Cheour et al., 1998; Kuhl & Coffey-Corina, 2001; Pegg & Werker, 1997; Rivera-Gaxiola et al., 2005; F. Tsao, Liu, Kuhl, & Tseng, 2000; Tsushima et al., 1994; J. F. Werker & Lalonde, 1988). Importantly, the discrimination of the retroflex and dental-stop consonants with an habituation procedure has been tested with English monolingual infants (Werker et al., 1981; Werker & Tees, 1984; Bruderer et al., 2015) and their results show that infants between 6 and 8 months discriminate the difference between both contrasts. Our results with Catalan and Spanish monolingual infants support the same results, suggesting that regardless of the specific language exposure, infants at 7 months are able to discriminate sounds they have never heard before. This concordance also constitutes a validation of the methodology we implemented, which is crucial as to establish an optimal framework for the results comparisons and interpretation of the results.

Second, and crucially, the results of Experiment 1 indicate that there were no differences in discrimination between bilingual and monolingual infants at 7 to 8 months of age. Both language groups maintained perceptual sensitivity to the nonnative retroflex contrast /Ta/. Therefore, the discrimination of such categories does not depend on the specific language exposure nor on whether there is one or two languages in the environment. Thus, we can conclude that linguistic experience does not alter the process of perceptual narrowing at 7 months. The present data answered our first experimental question by showing that until 7 months of age, the discrimination abilities of monolinguals and bilinguals proceed in parallel, regardless of their differences in exposure.

Werker and Tees (1984a) showed that monolingual infants loose their discrimination ability of consonants somewhat abruptly, at around 12 months of age. However, we have no information about the process of convergence in bilinguals. As previously argued, a study by Petitto et al. (2012) suggested that the case of bilinguals might be different, since their results implementing fNIRS brain imaging shows that the number of input languages in the infants' environment does change their neural processes. Their findings suggest that 10 to 12 month-old bilingual infants show robust neural activation to both the native and the nonnative phonetic contrasts, while monolingual infants show robust activation to the native phonetic contrasts only, and not to the nonnative phonetic contrasts. Despite the absence of information about how such differences impact at the behavioral level, their results indicate a possible discrimination of bilinguals at developmental stages at which monolingual infants can no longer discriminate. For this reason, we decided to implement the same methodology that was used in previous habituation paradigm experiments to contrast whether the differences in neural responses found with monolingual and bilingual infants also is actually in affecting their behavioral responses.

We now study whether also bilingual infants will lose sensitivity to nonnative contrasts by 12 months of age, in line with the results of studies by Werker et al. (1981) and Werker & Tees (1984) with monolinguals, or if, alternatively, the differences between monolingual and bilingual environments delay the closure of the process of phonetic narrowing.

2.2. Experiment 2: Discrimination of nonnative consonants at 12 months

In order to disentangle whether the differences in the linguistic environment influences the offset of perceptual reorganization, we tested two groups of one year-old infants raised in monolingual and bilingual homes with the same infant habituation procedure that was used in Experiment 1.

2.2.1 Methods

2.2.1.1 Participants

Forty-four 11;15 to 12;15 month-old infants (mean age 359 days, range 345 to 373) were included in the analysis. The monolingual group consisted of 18 monolingual infants (9 females) being raised in Catalan (n=10) and Spanish (n=8) monolingual environments. The bilingual group consisted of 26 infants (15 females) raised in bilingual Catalan-Spanish environments. All infants were full term with no reported health problems and were recruited from the same database as in the previous experiments. Thirty-two additional monolingual infants were tested but excluded from analysis due to the following reasons: fussiness (7), crying (9), not reaching the habituation criterion (5), short looking times in the post-test phase (1), parental interference (4), gaze out of camera (2), refusing to look to the screen (1), trilingual environment (3). Twenty-six additional bilingual infants were tested but excluded from analysis due to the following reasons: fussiness (7), crying (7), not reaching the habituation criterion (1), parental interference (2), absence of looking data due to the infants movements in test (1), experimenter error (1), trilingual environment (2), preterm infants (4), looking time in test trial inferior to 1s long (1). In test, half of the subjects in each language group were exposed to the Same-Switch condition and the other half to the Switch-Same condition. A parental consent and a language questionnaire were administered before each infant was tested.

2.2.1.2. Materials

The stimuli, apparatus and set-up were the same as in Experiment 1.

2.2.1.3. Procedure

The procedure was identical in comparison to Experiment 1.

2.2.2. Results

In the selection criteria for this experiment, we also included in the final sample of subjects infants who were habituated before block 2.

The justification for using a 3 block habituation is that if, for instance, the infant sneezes during an habituation trial and closes her eyes for a long period prior to the sneeze, the LT could fall to

60% of the looking time of the longest window of three trials, signaling habituation. However, those were very rare situations in our studies. Since at 12 months infants habituate faster and we wanted more sensitivity in test, we decided to avoid the unnecessary increase of the rejection rates with infants who performed good at the task. With the criterion change, including the infants who habituated to the background stimulus within the first six trials, 8 early habituating participants (6 monolinguals and 2 bilinguals) were added to the final sample.

A 2 (test trial type: pretest vs. posttest) x 2 (language group: monolingual vs bilingual environment) mixed design repeated-measures ANOVA with participants as random factor nested within language group was conducted in order to determine whether infants reduced attention during experiments, and whether a potential reduction in looking time between the pretest and posttest phase was equally affecting both language groups. There were no significant differences of language, test nor any interaction of language by test phase ($M_{Mon*PreTest}$ = 11.49 s, SE=0.40, $M_{Mon*PostTest}$ = 12.1 s, SE=0.98; $M_{Bil*PreTest}$ = 11.11 s, SE=0.28, $M_{Bil*PostTest}$ = 11.72 s, SE=0.25; $F(1, 42)=0.00004$, $p=0.99$), showing that infants in both groups did not reduce interest in a noticeable way from the beginning to the end of the experiment.

To address our main question of whether both language groups could discriminate the difference between a native and a nonnative contrast at 12 months, we conducted a 2 (test trial type: Same vs.

Switch) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable (see Figure 9). A main effect of test trial type emerged, (M_{Same} = 5.8 s, SE=0.31, M_{Switch} = 4.94 s, SE=0.36; F(1, 42)=6.48, p=0.01). Post-hoc Scheffe tests showed that, surprisingly, the longer looking pattern did not match the results commonly expected in visual habituation paradigms. The novelty effect of discrimination observed at 7 months is reverted by a familiarity effect at 12 months, with longer looking proportions to the screen during native trials ($M_{Same\text{-}Switch}$ = 0.87 s, SE=0.30, p=0.006).

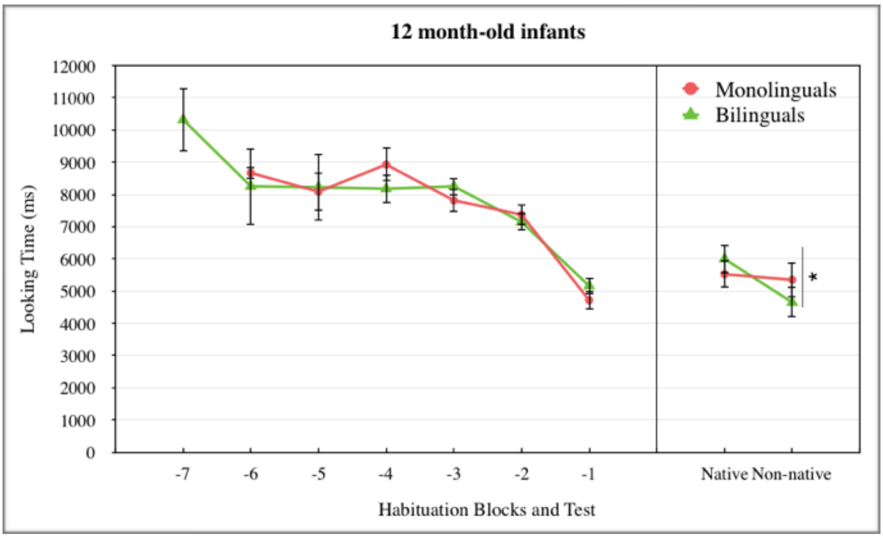

Figure 9. Mean looking times (in milliseconds) across habituation blocks and test trials in monolinguals and bilinguals at 12 months. Habituation blocks are numbered starting from the last habituation block to the first (backwards). Error bars represent standard errors.

Although there was no effect of language group, ($M_{Monolinguals}$ = 5.44 s, SE=0.34, $M_{Bilinguals}$ = 5.33 s, SE=0.34; F(1, 42)=0.03, p=0.85), there was a very strong trend towards an interaction between language and test trial, ($M_{Mon*Same}$ = 5.52 s, SE=0.42, $M_{Mon*Switch}$ = 5.35 s, SE=0.55, $M_{Bil*Same}$ = 6 s, SE=0.44, $M_{Bil*Switch}$ = 4.65 s, SE=0.48; F(1, 42)=0.62, p=0.055). Although the strength of the effect does not allow us to state that the statistical interaction was significant, we equally conducted Scheffe post-hoc comparisons for a better understanding of the discrimination patterns corresponding to each language group. The monolingual group did not discriminate between test trials (M=-0.17 s, SE=0.46, p=0.71), while the bilingual group showed a strong discrimination response, with a longer looking proportion in the Same trials (M=1.35 s, SE=0.38, p=0.001). Therefore we can tentatively conclude that the previously mentioned main effect of trial type at 12 months was driven by the task performance of the bilingual group.

For the same reasons as in Experiment 1, that is, in order to observe whether the order of the 2 conditions had an impact on the results, we conducted a 2 (order condition: Same-Switch and Switch-Same) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. As shown in Figure 10, there was no interaction of order condition and language group ($M_{Mon*SameSwitch}$ = 5.37 s, SE=0.53, $M_{Mon*SwitchSame}$ = 5.50 s, SE=0.45, $M_{Bil*SameSwitch}$ = 5.16 s, SE=0.48,

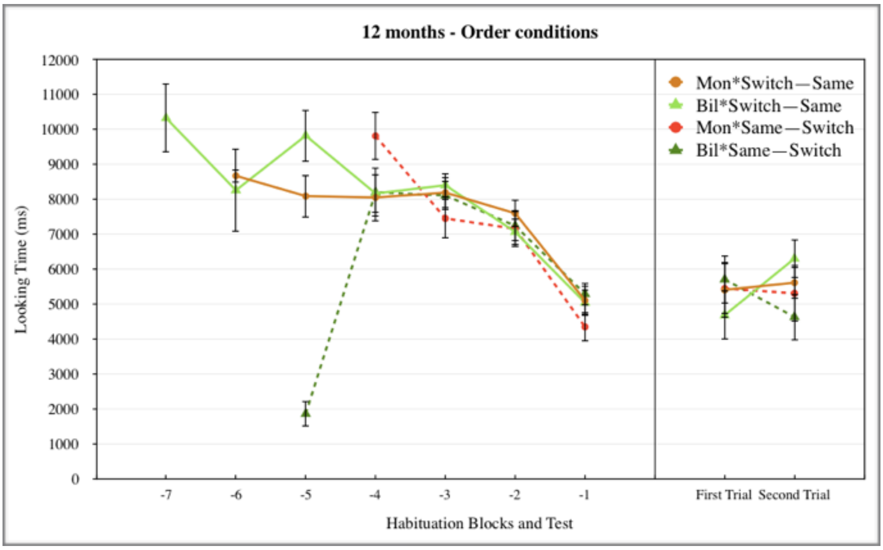

Figure 10. 12-month-old monolingual and bilingual infants' mean looking times (in milliseconds) are depicted by test conditions (Same-Switch and Switch-Same). Habituation blocks are numbered starting from the last habituation block to the first (backwards) and the test phases are presented by order of presentation (first or second). Error bars represent standard errors.

$M_{Bil*SwitchSame}$ = 5.49 s, SE=0.47; $F(1, 44)=0.02$, $p=0.88$). Nonetheless, since the bilingual group showed an increase in looking times to the screen during the Same trials, we conducted an analysis exclusively with the bilingual sample, with a 2 (order condition: Same-Switch and Switch-Same) x 2 (test trial type: Same vs. Switch) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. Bilinguals' longer looks to the Same trials were not predicted by the order condition ($M_{SameSwitch*Same}$ = 5.70 s, SE=0.70, $M_{SwitchSame*Same}$ = 6.30 s, SE=0.56, $M_{SameSwitch*Switch}$ = 4.62 s, SE=0.67, $M_{SwitchSame*Switch}$ = 4.68 s, SE=0.71; $F(1, 24)=0.55$, $p=0.47$). That is, regardless of the order condition, bilinguals looked longer to the dental trials.

Given that all bilingual infants were habituated to the Same trials and in test they showed a familiarity preference towards the Same trials, we conducted follow-up analysis for further comprehension of such unusual response.

Bosch & Sebastián-Gallés (2003) and Sebastián-Gallés & Bosch (2009) showed that when using a familiarization-preference procedure (Jusczyk & Aslin, 1995) to assess discrimination, Catalan-Spanish bilingual infants are able to discriminate native vocalic contrasts at 4 months and 12 months but they do not at 8 months. However, when the same sound categories used in the study by Bosch & Sebastián-Gallés (2003) were tested with 8-month-old bilinguals using an anticipatory eye movement task, infants showed discrimination (Albareda-Castellot, Pons, Sebastián-Gallés, 2011). The comparison of such results show that implementing a measure based on the recovery of attention can lead to present genuine patterns in bilinguals which do not necessarily correlate with their perceptual capacities but, more likely, with their attentional resources at certain developmental stages. For this reason, we conducted further analysis with the data of 12 month-old bilinguals.

First, we aimed at ensuring that the looking times of bilinguals when the Same trial appeared first in test were not due to differences in the perception of the habituation task in 12 month-old bilinguals in comparison to monolinguals, resulting in attentional differences between groups. We wanted to discard the possible pattern of an attentional drop during habituation and a posterior regain of attention unrelated to the stimuli being presented. In such case we would have predicted higher values in the first test trial than in the last trial of habituation, regardless of the trial kind.

Therefore, we compared bilinguals' looking time proportions to the last trial of habituation and the two test trials for each experimental condition. A 3 (test trial type: Last habituation trial, first test trial, second test trial) x 2 (order condition: Same-Switch and Switch-Same) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. There were no main differences in looking times between trials nor any effect of order. However, an interaction of order by trial emerged ($M_{LastHabTrial*SameSwitch}$ = 4.86 s, SE=0.61, $M_{LastHabTrial*SwitchSame}$ = 4.61 s, SE=0.57, $M_{FirstTestTrial*SameSwitch}$ = 5.70 s, SE=0.70, $M_{FirstTestTrial*SwitchSame}$ = 4.68 s, SE=0.71, $M_{SecondTestTrial*SameSwitch}$ = 4.62 s, SE=0.67, $M_{SecondTestTrial*SwitchSame}$ = 6.30 s, SE=0.56; $F(2, 48)=4.76$, p=.008).

Since infants looking proportions differed as a consequence of the interaction of trial kind and order, post-hoc Scheffe comparisons followed. First, we found a significant difference between the last trial of habituation and the Same trial only when it was shown second in test, that is, when it was presented after the Switch, (M=1.69 s, p=.026), but no differences between the last test trial of habituation and the Same trial when it is presented first in test (M=0.85 s, p=0.38). Therefore, we can conclude that here was not an spurious enhanced reaction to the native sounds right after the habituation. The last trial of habituation and the Same test trial in test are different only when the Same trial appears after the Switch.

Second, we also compared if the familiarity effect was related to the type of stimuli presented in the preceding trial, it being a Same or a Switch trial. Directional asymmetries are shown when discrimination of a change in one direction results in significantly better performance than in the other direction. Perceptual asymmetries have been observed in infants tested in both vowel (Mugitani, Kobayashi, & Hiraki, 2008; Polka & Bohn, 2003, 1996; Pons, Albareda-Castellot, & Sebastián-Gallés, 2012) and consonant (Kuhl et al., 2006) discrimination studies. The designs of these studies consist of habituating infants to one contrast and the other half to the other contrast and then observing whether they react to a sound category change similarly or whether one of the two directions is harder to discriminate. The interpretation of the results obtained by (Pons et al., 2012) with Spanish-learning infants at 12 months, suggests that, only after perceptual reorganization, can the frequency of occurrence of a vowel make it to act as a referent in the discrimination task and elicit discrimination only in the direction of the most frequent contrast in the infants' phonetic repertoire.

Although the differences between our design and the paradigms testing for asymmetry do not allow us to establish a direct comparison of the results between studies -since we did not have a condition in which infants habituate to the nonnative retroflex contrast-, the alternation of trial order in test could influence infants' responses. Hence, if the logic of their interpretation applied in the case of the familiarity preference observed in our Experiment 2, we could find a different reaction to the Same trial depending on which trial is preceding. Thus, we might expect a higher discrimination response to the native sounds when the direction of the presentation is nonnative-native (Switch-Same), that is, when the nonnative less frequent sound precedes the more frequent category, than when the direction of the presentation is native-nonnative (Same-Switch), when the direction goes from more to less frequent.

Summarizing, a possible explanation for the familiarity preference pattern of bilinguals at that same age could be that, despite the fact that all infants were exposed to the native (Same) trials during habituation, in test they show a preference for their more frequent - and therefore easier to be processed- native sound.

Consequently, as to determine whether the strength of discrimination between trial types differed between the first or second test presentation in bilinguals, we conducted another 2 (order condition: Same-Switch and Switch-Same) x 2 (test trial order: First and Second) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. A significant interaction emerged, that is, depending on the experimental condition (Same-Switch or Switch-Same), the first and second trial looking times values differed according to which trial type was presented ($M_{SameSwitch*First}$ = 5.70 s, SE=0.70, $M_{SameSwitch*Second}$ = 4.62 s, SE=0.68, $M_{SwitchSame*First}$ = 4.68 s, SE=0.71, $M_{SwitchSame*Second}$ = 6.30 s, SE=0.56 ; $F(1, 24)=13.44$, p=0.001). The Scheffe post-hoc comparisons for these analysis revealed a difference between the native and nonnative contrasts in both the Switch-Same condition (M=1.62, SE=0.52, p=0.004) and the Same-Switch condition (M=1.08, SE=0.52, p=0.05). Also comparisons between the Same and Switch trials in first or second position revealed a tendency towards discrimination of contrasts when they appear first in test (M=1.02, SE=0.52, 0.061), but differences sharpened when the two contrasts are compared in the second order of presentation (M=1.67, SE=0.52, p=0.004).

Together, these results suggest that an asymmetry effect of direction based on frequency of occurrence of the sounds could be explaining infants familiarity preference at 12 months, since infants increase their preference for to the native sounds only after the presentation of a nonnative unfrequent sound. The fact that our data coincides with the same pattern of discrimination observed with Spanish infants at 12 months on native vowels, suggests that both phoneme frequency and age could be relevant factors to account for the results.

Finally, separate analysis checked the effects of gender and age, to ensure that there were not additional interactions, and we also explored whether the number of habituation blocks was different between language groups as to determine whether infants showed different patterns of habituation as a function of their linguistic background. We found no effects of these variables.

2.2.3. Discussion

The current results shed new light onto our experimental question. While at 12 months of age monolingual infants no longer show discrimination between native and nonnative contrasts, bilingual infants are still able to discriminate the difference at this developmental stage, although, surprisingly, with longer looking times to the native trial sound they had been habituated to. Such unexpected behavioral pattern of bilinguals shows that a Catalan-Spanish bilingual environment alters the timing of phonetic narrowing when compared to corresponding monolingual environments. Furthermore, it also shows that at 12 months when bilinguals discriminate between a phoneme of their language and a phoneme not represented in it, they do it so by increasing interest towards their native sound especially after they have been exposed to a non-native sound, as if they preferred to listen to their native sounds after listening to an odd sound not belonging to the category. Our findings can lead to four possible interpretations.

A first possibility could be that infants are showing a broad-based phonetic sensitivity despite of the direction of the effect. Importantly, the direction of a looking preference is largely irrelevant when infants' discrimination ability or recognition memory is of primary interest; any deviation from random behavior indicates that a difference between the stimuli has been detected. The difference in the directionality of their pattern could then be an effect of age. It has been suggested that development plays a role in the kind of preference effects, claiming that familiarity effects precede novelty effects (Pascalis & de Haan, 2003). However, since at 7 months we found a main effect of discrimination with a novelty preference pattern and there were no difference between language groups, the developmental approach can not explain the transition from novelty to familiarity between 7 and 12 months in bilingual-leaning infants. Hence, we cannot claim that the age factor is, at least exclusively, accounting for their familiarity pattern.

A second possibility could be that 12 month-old bilingual infants have already started the process of perceptual narrowing. Then the differences in information encoding might explain the familiarity preference patterns. According to Bahrick & Pickens (1995), familiarity preferences occur when internal representations are discrepant from the external stimulus, either because the internal representation has faded or because the stimulus is not yet fully encoded. In the case of our results with bilinguals, if the category is incompletely encoded, the infant will show a familiarity preference. Conversely, if the category is totally encoded, the infant will show a novelty preference. Following this assumption, Spanish-Catalan bilinguals would be in the process of acquiring the representation of the category at 12 months and, thus, the familiarity preference would then emerge.

Third, the possibility that encoding at 12 months is different in bilinguals and, therefore leads to a familiarity preference as opposed to a novelty preference, could also be explained by the attentional resources of bilinguals at this particular age. Previous studies suggest that bilingualism impacts the attentional system's ability to detect and remember perceptual information (Sebastián-Gallés et al., 2012). It could be that the increased demands bilingualism imposes to executive functions, in comparison to the demands of monolinguals, may have an impact on the performance of infants with this particular task.

Given that at 7 months infants showed discrimination with a novelty preference, the three above-mentioned assumptions should also need to be complimented with an additional explanation for the younger age group of bilinguals. Unlike 12-month-olds, younger infants would perform the task on the basis of their broad-based phonetic sensitivity. In all cases, the switch from novelty to familiarity preference would depend on the type of information that the perceptual system is computing. That is, when at 7 months perceptual narrowing has not started yet, the novelty preference might be performed over the perception of the broader initial biases. In contrast, when at 12 months the perceptual narrowing has already started, discrimination might be performed on the basis of an incomplete representation of the language-specific category and consequently, the familiarity preference may arise on the basis of such novel perceptual set up.

A forth possibility could be that bilinguals' performance at 12 months is affected by a positive affect towards their native language. Nachman, Stern, & Best et al. (1986) suggest that infants who show positive affect during familiarization may form less complete internal representations of the stimulus during the task and, thus, are more likely to show familiarity preferences when compared to infants who show neutral affect.

Therefore, our results with 12 month-old infants don't allow us to drive major inferences about the stage of their perceptual narrowing process. The particular familiarity effect observed in bilinguals in Experiment 2 could be interpreted as an absent or already ongoing process of perceptual narrowing in this group. Therefore, we decided to conduct another study with older infants, at 15 months of age. Possibilities are that at a later developmental stage bilingual infants either lose the discrimination to nonnative contrasts, by finally showing the same pattern of monolinguals at 12 months, or either that they maintain discrimination. In the case of showing evidence for discrimination at 15 months, we could also expect two different scenarios, one in which the familiarity pattern is maintained, and another one in which they show a reversed pattern of discrimination with a novelty preference prior to convergence. If the familiarity pattern was maintained at 15 months, we might be inclined to think that the affective theory is the most suitable explanation for the results at 12 and 15 months. If the novelty preference follows 3 months later in development, then we would be more inclined to state that the differences in the type of information that is encoded are accounting for the differences in infants' responses between 7, 12 and 15 months.

2.3. Experiment 3: Discrimination of nonnative consonants at 15 months

The following experiment was aimed at determining whether the behavioral differences in perceptual sensitivity observed between monolingual and bilingual infants at 12 months are still observable 3 months later in development or whether, alternatively, bilingual infants also show loss of discriminability to nonnative consonant contrasts at 15 months. In order to establish which of the two possibilities was true we tested the two language groups, monolingual and bilingual infants, with the same task used in Experiment 1 and Experiment 2.

2.3.1. Methods

2.3.1.1. Participants

Forty-four 14;15 to 15;15 month-old infants (mean age 451 days, range 435 to 469) were included in the final analysis. Twenty-two Catalan (n=16) and Spanish (n=6) monolingual infants (12 females) successfully completed the study and 22 Catalan-Spanish bilingual infants (10 females). An additional 21 monolingual infants were tested but excluded from analysis due to fussiness or crying (14), short looking times in the post-test phase (1), experimenter or technical error (2), parental interference (2), exposure to other languages different than Spanish or Catalan (2). Ten additional bilingual infants were also tested but excluded from analysis due to fussiness (6), crying (1), not reaching the habituation criterion within less than 24 trials (1), parental interference (2). In test, half of the subjects in each language group were exposed to the Same-Switch condition and the other half to the Switch-Same condition. All infants were full term with no reported health problems and were recruited from the same database as in the previous experiments. As in the previous experiments, a parental consent and a language questionnaire were administered before each infant was tested.

2.3.1.2. Materials

The stimuli, apparatus and set-up were the same as in Experiment 1 and 2.

2.3.1.3. Procedure

The apparatus and procedure were identical to those used in Experiment 2.

2.3.2. Results and discussion

A 2 (test trial type: pretest vs. posttest) x 2 (language group: monolingual vs bilingual environment) mixed design repeated-measures ANOVA with participants as random factor nested within language group was conducted in order to determine whether infants reduced attention during experiments, and whether a potential reduction in looking time between the pretest and posttest phase was equally affecting both language groups. There were no significant differences of language, test nor any interaction of language by test phase ($M_{Mon*PreTest}$ = 11.73 s, SE= 0.17, $M_{Mon*PostTest}$ = 12 s, SE=0.16; $M_{Bil*PreTest}$ = 11.63 s, SE= 0.27, $M_{Bil*PostTest}$ = 11.92 s, SE= 0.24; $F(1, 42)=0.05$, $p=0.82$), showing that infants in both groups did not reduce interest in a noticeable way from the beginning to the end of the experiment.

To address our main question of whether both language groups could discriminate the difference between a native and a nonnative contrast at 15 months, we conducted a 2 (test trial type: Same vs. Switch) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. An effect of language group emerged ($M_{Monolinguals}$ = 4.85 s, SE=0.31, $M_{Bilinguals}$ = 6.18 s, SE=0.32; $F(1, 42)=8.58$, $p=0.006$) revealing a difference in proportion of looking times between language groups (see Figure 11). Post-hoc comparisons showed that overall bilinguals looked longer than monolinguals in test (M=1.33, SE=0.46, p=.005). There was no main effect of trial kind but the interaction between language and test trial was significant, ($M_{Mon*Same}$ = 5.03 s, SE=0.49, $M_{Mon*Switch}$ = 4.67 s, SE=0.39, $M_{Bil*Same}$ = 5.34 s, SE=0.46, $M_{Bil*Switch}$ = 7.03 s,

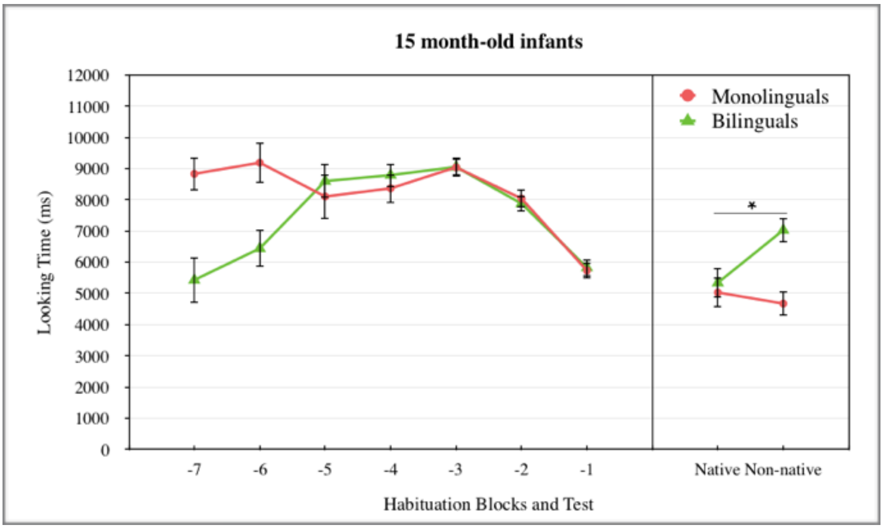

Figure 11. Mean looking times (in milliseconds) across habituation blocks and test trials in monolinguals and bilinguals at 15 months. Habituation blocks are numbered starting from the last habituation block to the first (backwards). Error bars represent standard errors.

SE=0.38; *F*(1, 42)=6.27, p=0.02), showing that the two groups reacted to the test trials differently. Post-hoc comparisons confirmed that monolinguals did not show differences in looking times between test trials (M=-3.56, SE=-0.58, p=0.54), while the bilingual group showed a strong discrimination response, with longer looking proportion in the Switch trials (M=1.70 s, SE=0.58, p=0.006). The looking proportion to the retroflex differed between groups (M=2.35 s, SE=0.58, p=0.0002). That is, only bilinguals showed dishabituation to the nonnative contrast /Ta/ by looking significantly longer to the screen during the Switch test trials. In order to observe whether the order of the 2 conditions had an impact on the results, we conducted a 2 (order condition: Same-Switch and Switch-Same) x 2 (language group: monolingual vs bilingual environment) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. As shown in Figure 12, there was no interaction of order condition and language group ($M_{Mon*SameSwitch}$ = 4.68 s, SE=0.38, $M_{Mon*SwitchSame}$ = 5.02 s, SE=0.49, $M_{Bil*SameSwitch}$ = 6.13 s, SE=0.45, $M_{Bil*SwitchSame}$ = 6.23 s, SE=0.47; $F(1, 40)=0.07$, p=0.79).

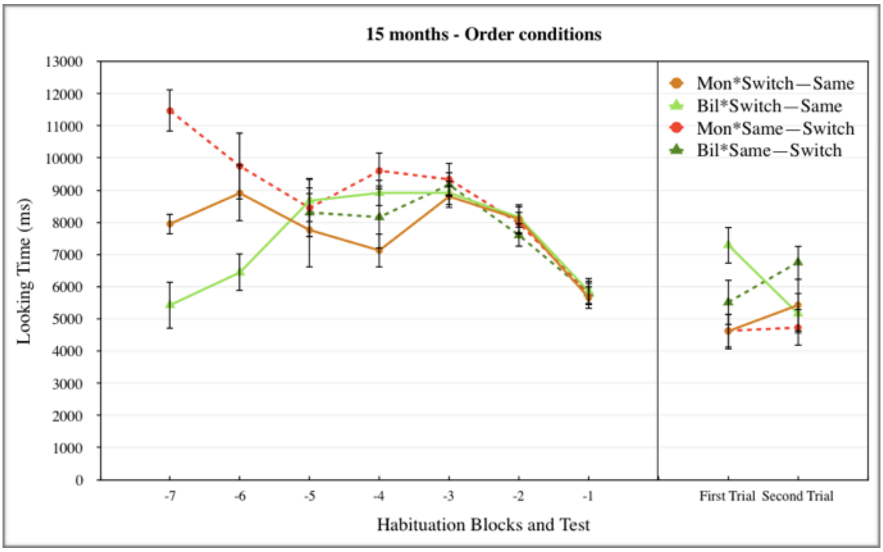

Figure 12. 15-month-old monolingual and bilingual infants' mean looking times (in milliseconds) are depicted by test conditions (Same-Switch and Switch-Same). Habituation blocks are numbered starting from the last habituation block to the first (backwards) and the test phases are presented by order of presentation (first or second). Error bars represent standard errors.

To determine whether in bilinguals the strength of discrimination between trial types differed during in the first or second test presentation, we conducted another 2 (order condition: Same-Switch and Switch-Same) x 2 (test trial order: First and Second) mixed model ANOVA, with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. A significant interaction between emerged, that is, depending on the experimental condition (Same-Switch or Switch-Same), the first and second trial looking time values differed according to which trial type was presented ($M_{SameSwitch*First}$ = 5.51 s, SE=0.71, $M_{SameSwitch*Second}$ = 6.8 s, SE= 0.53, $M_{SwitchSame*First}$ = 7.3s, SE= 0.57, $M_{SwitchSame*Second}$ = 5.16 s, SE= 0.63; $F(1, 20)=7.02$, p=0.02). The Scheffe post-hoc comparisons conducted with the bilingual group revealed a difference between the native and nonnative contrasts only in the Switch-Same condition (M=-2.13 s, SE=0.9, p=0.03) and not in the Same-Switch condition (M=1.24 s, SE=0.9, p=0.18). That is, discrimination between native and nonnative trials emerged only when the nonnative contrast was presented first in test. Also comparisons between the Same and Switch trials in first or second position revealed a tendency towards discrimination of contrasts when they appear first in test (M=-1.78 s, SE=0.90, p=0.062), but no differences emerged when the two contrasts were compared in the second order of presentation (M=1.59 s, SE=0.90, p=0.09). That is, in both cases there was a tendency of differences between looking times to the native and nonnative contrasts, slightly more marked when the nonnative sound was presented in the first position.

In order to assess whether the null discrimination pattern of monolinguals was equivalent at 12 and 15 months we also compared the results of both age groups 2 (age: 12 months and 15 months) x 1 (language group: monolinguals) with an analysis of variance (ANOVA), with participants as random factor nested in groups, and looking proportion to the test trials as the dependent variable. There was no main effect of age, nor any interaction between the age of the experiment and trial kind.

Finally, separate analysis checked the effects of gender and age, to ensure that there were not additional interactions, and we also explored whether the number of habituation blocks was different between language groups as to determine whether infants showed different patterns of habituation as a function of their linguistic background. We found no effects of these variables.

2.3.3. Discussion

The results of Experiment 3 indicate that at 15 months of age the perceptual abilities of bilingual and monolingual infants differ. While monolingual infants at 15 months do not discriminate nonnative consonants, as 12-month-olds monolinguals, 15 month-old bilingual infants maintain such ability. At the same time, the pattern of discrimination of the bilingual group at 15 months changes with respect to 12 month-olds. Bilinguals at 12 months look longer to the native sound to which they had been habituated. We suggested possible interpretations for the familiarization pattern of younger infants, as evidence of a stage before or during perceptual reorganization.

As discussed, the sharp novelty preference shown by bilinguals at 15 confirms that at 12 months the category for the native dental sounds was not fixated yet. Both the differences in the type of information that is encoded and age in development may be accounting for the differences in infants' responses between 7, 12 and 15 months. That is, at 7 months the novelty preference may reveal a distinction based on broad-based initial sensitivities. Three months later, at 12 months, infants are in the process of extracting the category of their native sounds, and for this reason they recover interest to a native phoneme after a non-native sound has interrupted a sequence of within-category sounds the category formation. At 15 months such pattern is reverted showing a more mature response of discrimination with longer looks to the nonnative trials, in agreement with the age theories which predict switches from familiarity to novelty preferences throughout the course of development.

Familiarity effects also have been found in 12-month-old monolingual populations, in phonetic discrimination and word segmentation studies using behavioral and ERP techniques (Cheour et al., 1998a; Rivera-Gaxiola et al., 2005; Bosch et al., 2013). A recent study by Kouider et al. (2015) shows similar effects with a non-linguistic task. The authors tested 12-month-old infants with a violation of expectation task and found early attentional amplification of neural activity to expected events, and a late neural amplification to surprising unexpected events. They claim that topdown impact of prior expectations occur at early, local, and non-conscious stages of neural activity in sensory cortex. And conversely, later processing stages might involve large-scale computations and are associated with perceptual consciousness. Relating their results to our study, it could be the case that at 15 months, bilingual infants are showing a conscious change detection response in comparison to the non-conscious reaction to a change at 12 month-olds. Hence, changes in the domain general cognitive mechanisms at 12 months could also explain our results.

Finally, the possibility that differences in encoding between 12 and 15 months rely on the attentional resources available in infants at these two ages remains open. If bilinguals' attentional resources were different at 12 than than at 15 months, the impact of attention on the process of encoding information could also explain the shift in the pattern of preference.

Hence, and as shown by Albareda et al. (2011), further studies using a task in which attention recovery is not at play, in contrast with the current habituation procedure, might be a means for observing the consistence of infants' discrimination responses regardless of the directionality of the effects.

In sum, the bilingual shift from a familiarity preference pattern of discrimination to a novelty preference pattern reveals that in bilinguals the perceptual reorganization is still an ongoing process, and also that this process is more dynamic than that of monolingual infants. The present data continues to answer our second experimental question by showing that bilingualism delays for at least more than 3 months the offset of perceptual sensitivity to the nonnative contrast /Ta/ with respect to monolinguals. However, the answer to when phonetic narrowing process concludes in bilinguals remains open. For this reason we decided to test an extra group of bilingual infants 3 months later, at 18 months.

2.4. Experiment 4: Discrimination of nonnative consonants at 18 months

The goal of the current experiment was the same as in Experiment 3. Our previous results showed that monolinguals did not discriminate both at 12 and at 15 months with no significant differences between both ages. Such findings are in line with the studies that show that discrimination of nonnative consonants is lost until adulthood (Werker et al., 1981). In contrast, 15 month-old bilingual infants maintained sensitivity to the nonnative contrast by presenting a novelty preference response, which drastically differed from the familiarity preference response observed at 12 months. For the above mentioned reasons, our question for this experiment was exclusively focused on the bilingual infants' behavior. Bilingual infants were tested 3 months later, at 18 months, with the same paradigm that was used in the previous studies.

2.4.1. Methods

2.4.1.1. Participants

Twenty healthy full-term infants (13 females) raised in Catalan-Spanish bilingual environments between the ages of 17;15 to 18;15 months (mean age 545,68 days, range 536 to 555 days). All subjects were recruited from the same database as in the previous experiments. Seventeen additional infants were tested but excluded from the final sample for the following reasons: not habituated (2), fussiness (7), crying (1), experimenter or technical error (1), parental interference (1), being raised in monolingual environments (7). Ten subjects were exposed to the Same-Switch condition and ten other subjects to the Switch-Same condition, after the language questionnaire was administered and the parental consent was signed.

2.4.1.2. Materials

The stimuli were the same as in Experiment 1, Experiment 2 and Experiment 3.

2.4.1.3. Procedure

The apparatus and procedure were identical to those of Experiment 2 and Experiment 3.

2.4.2. Results

A repeated-measures ANOVA was conducted to determine whether looking times between the pretest and posttest phase were equivalent in the 18 month-old group. There were no significant differences between such test phases, $F(1, 19)=2.49$, $p=0.13$, showing that infants were not disinterested or fatigued after running the study.

A one-way analysis of variance (ANOVA) with test trial type (pretest vs. posttest) as independent variable, bilingual participants as random factor, and looking proportion to the test trials as the dependent variable, was conducted in order to determine whether infants reduced attention during the experiment. There were no significant differences of test ($M_{Bil*PreTest}$ = 11.43 s, SE=0.29, $M_{Bil*PostTest}$ = 11.43 s, SE=0.12; $F(1, 19)=2.49$, p=0.13), showing that infants did not reduce interest in a noticeable way from the beginning to the end of the experiment.

To address our main question of whether bilingual infants at 18 months could discriminate the difference between a native and a nonnative contrast, an analysis of variance (ANOVA) with test trial type (test trial type: Same vs. Switch) as a within-participants factor

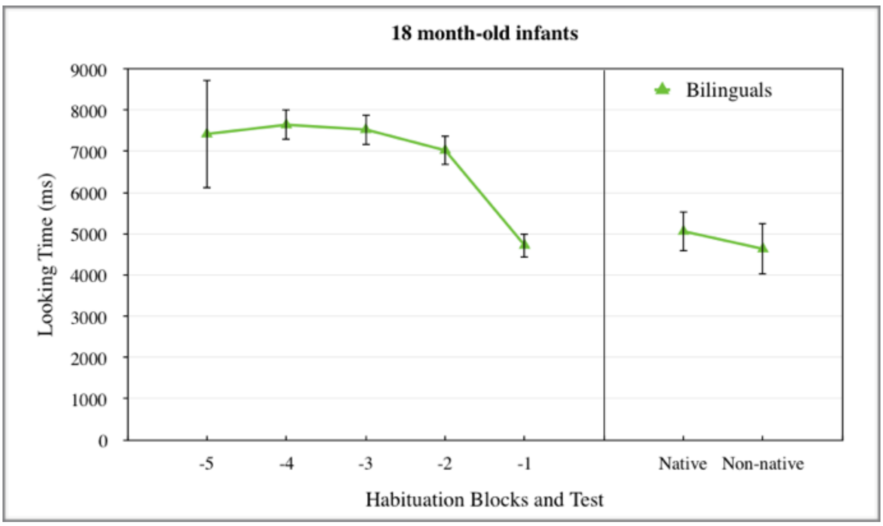

Figure 13. Mean looking times (in milliseconds) across habituation blocks and test trials in bilinguals at 18 months. Habituation blocks are numbered starting from the last habituation block to the first (backwards). Error bars represent standard errors.

and participant as random variable was performed on mean looking time scores. No main effect of test trial type emerged, (M_{Same} = 5.06 s, SE=0.49, M_{Switch} = 4.63 s, SE=6.20, $F(1, 19)=0.36$, p=0.55 (see Figure 13). That is, 18 month-old bilinguals did not discriminate the difference between native and nonnative sounds.

In order to observe whether the two order conditions were not affecting infants' responses differently, we conducted a 2 (order condition: Same-Switch and Switch-Same) x 2 (test trial type: Same vs. Switch) mixed model ANOVA, with participants as random factor nested in order condition group, and looking proportion to the test trials as the dependent variable. As shown in Figure 14, there was no interaction of order condition ($M_{Bil*SameSwitch}$ = 5.10 s, SE=0.52, $M_{Bil*SwitchSame}$ = 4.64 s, SE=0.57; $F(1, 18)=0.28$, p=0.6).

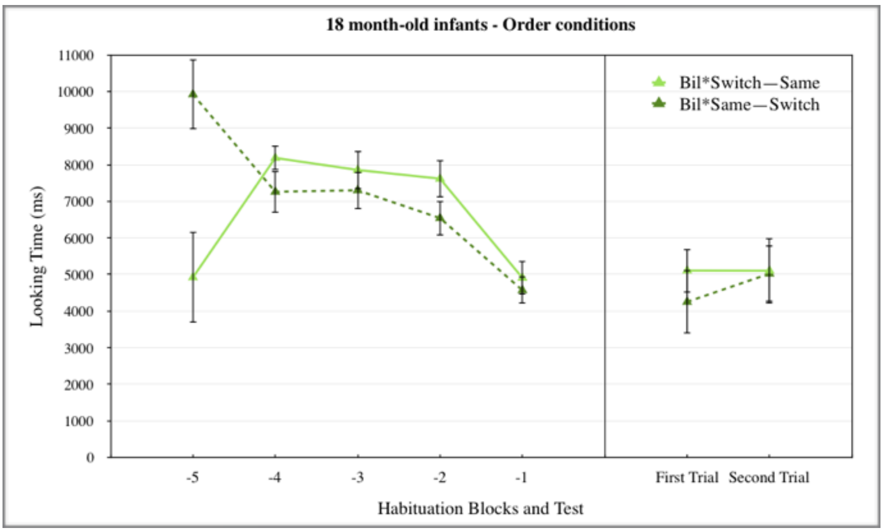

Figure 14. 18-month-old bilingual infants' mean looking times (in milliseconds) are depicted by test conditions (Same-Switch and Switch-Same). Habituation blocks are numbered starting from the last habituation block to the first (backwards) and the test phases are presented by order of presentation (first or second). Error bars represent standard errors.

Finally we checked that there was no main effects of gender.

2.4.3. Discussion

Experiment 3 allows us to conclude that bilinguals cease to discriminate the native vs nonnative consonant contrast at 18 months. The same behavioral pattern observed with monolingual infants at 12 months. Therefore, in response to our experimental question, we can conclude that the bilingual experience extends the perceptual sensitivity period of nonnative consonants by 6 additional months in comparison to infants exposed to monolingual environments.

2.5. Chapter discussion

The initial match between monolingual and bilingual infants in sensitivity of nonnative contrasts shows that linguistic experience does not alter the onset of perceptual narrowing. The extended pattern of reorganization of consonants in bilinguals allows us to observe differences in the dynamics of discrimination between 7, 12 and 15 months when infants are tested with a visual habituation procedure. Their novelty-familiarity-novelty response suggests that bilingual infants might be processing different information across development. At 7 months, they discriminate the difference on the basis of broad-based sensitivities. The familiarity effects at 12 months show that not only that the perceptual space of bilingual infants has already started the process of reorganization but also that they could already be representing a more complex proto-category, since they prefer to attend to the more familiar native contrast in test. At 15 months, their discrimination pattern shifts again. However, we can not ensure whether their results show a still ongoing narrowing process or if, alternatively, they have already acquired their native category and their heightened acoustic or attentional skills allow them to still react to nonnative sounds. Nonetheless, and as expected from the results with Catalan-Spanish bilingual adults (Burfin et al., 2014), the lack of discrimination response at 18 months confirms the final convergence of the dental-retroflex consonant category and sets the same final stage of narrowing than monolinguals 6 months later (Figure 15).

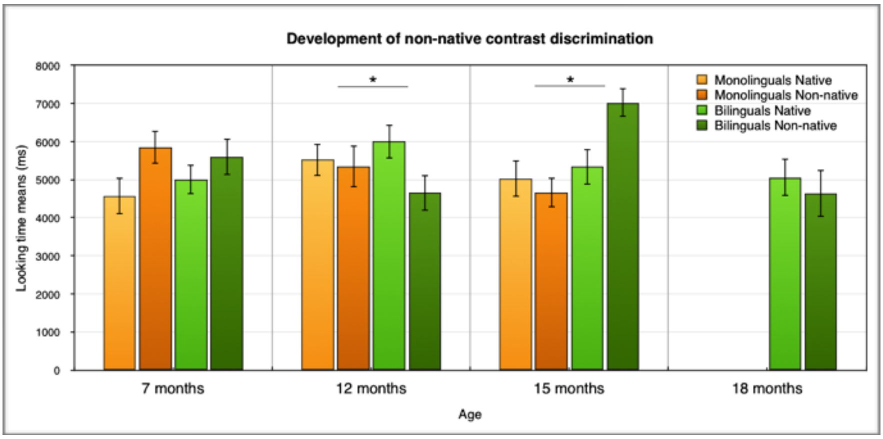

Figure 15. Summary of mean looking times (in milliseconds) to the native and nonnative trials across experiments for monolingual and bilingual groups. Error bars represent standard errors.

Importantly, taking together the differences in the dynamics of nonnative sensitivity between groups, we can discard the hypothesis that maturation overrides experience in the case of bilingual contexts. Hence, we finally conclude that the maturational development of infants is shaped by their linguistic experience.

Therefore, the different course of phoneme discrimination in bilingual infants is either a consequence of the restricted frequency of occurrence of sounds (Anderson et al., 2003), of attention (Sebastián-Galles et al., 2012), or of a delay in the offset of the critical period (Werker & Hensch, 2014).

We initially discarded the input frequency as a possible cause to account for differences in perceptual narrowing between monolinguals and bilinguals due to the similarity of the frequency of occurrence of the native category in the Catalan and Spanish language.

Regarding the attentional hypothesis, in our results we did not find differences in the length of habituation phase nor main effects of overall looking times to the screen. However, we did obtain differences in the rejection rates between language groups. Considering all samples, the attrition rates corresponding to infants who did not finish the experiment or who were rejected due to the fussiness criteria, were 25% lower in the case of bilingual infants. That is, 25% more bilingual infants successfully completed the experiment than monolingual infants. Furthermore, the ratio of exclusion was similar across ages (see Figure 16). Therefore, we can not discard the attentional hypothesis as the cognitive difference

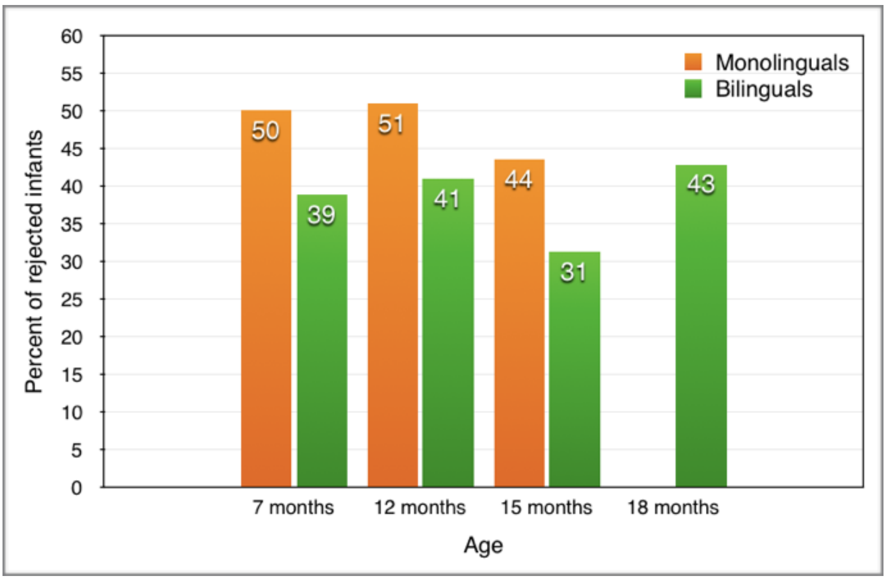

Figure 16. Percentage of monolingual and bilingual infants rejected by age of experiment. The numbers in the bars correspond to the absolute number of infants that were excluded from the sample.

accounting for the results between language groups. In the case that our effects are showing a higher interest of bilingual infants towards this specific linguistic task, we should properly test the attentional hypothesis to disentangle the causes of such differences. Additional studies should be conducted to equate the interest of both language groups in the task, either by engaging monolingual infants in a reinforced linguistic task or either by testing both groups with the same Switch habituation paradigm but using non-linguistic stimuli such as tones.

As for the critical period hypothesis, our data suggests it should still be a considered a possible cause of the differences in discrimination between groups. Ultimately, the effects of bilingualism on the critical period should be investigated with the appropriate experimental methodology, and desirably, throughout the obtention of biological or electrophysiological markers that correlate with the offset of the critical period.

3. INFLUENCES OF THE TYPE AND DEGREE OF LANGUAGE INPUT ON PERCEPTUAL REORGANIZATION

3.1. Degree of bilingualism and discrimination

In the previous chapter we reported that monolingual and bilingual infants share the same initial sensitivities for nonnative consonants at 7 months. Nonetheless, in monolingual infants the decay of nonnative consonant discrimination lasts for 4 months, whereas the same process in bilingual infants lasts for 10 months. Hence, we concluded that bilingualism abruptly influences the process of phonetic reorganization. However, it still remains a mystery if the impact of bilingualism is qualitative or quantitative. That is, from our previous results we can not determine whether our categorical variable of bilingualism triggers similar differences in discrimination responses or, alternatively, whether the gradual increase in exposure to two languages predicts an increase in the degree of discrimination. Moreover, and in contrast with other experimental populations, we can explore such quantitative effects of bilingualism due to the characteristics of our sample. As before mentioned, in our sample we only accepted participants who were exposed to Catalan and/or Spanish, and both culture and socio-economic status are equated in our population. Hence, the degree of bilingualism can appropriately be explored without presenting confounds.

Hence, in this chapter we conduct a series of finer-grained analysis to detect whether the continuum between full exposure to only one language and equidominant exposure to two languages positively correlates with lower to higher responses in discrimination.

3.1.1. Results

We analyzed whether the degree of bilingualism influenced infants' discrimination of nonnative contrasts for the samples of Experiment 1, Experiment 2 and Experiment 3. Unlike Experiment 4, the previous three samples were comparable in terms of language variability and size.

In order to determine whether the amount of bilingual exposure had a gradual effect over discrimination, a regression analysis was conducted for each age, using discrimination scores (difference in looking times between Same and Switch trials) as the outcome and degree of bilingualism as a predictor. The variable degree of bilingualism was computed on the basis of percentage of exposure to the dominant language (L1), with a range of values between 50%-bilingual infants with equivalent amount of exposure to both of their languages-, and 100% -monolingual infants with null exposure to a second language-.

As shown in the previous chapter, at 7 months there were no differences in discrimination between language groups. Accordingly, the regression analysis conducted with 7-month-old infants revealed that the degree of bilingualism did not have effects over infants' discrimination scores, R^2=1.5%, $F(1, 42)=0.64$, p=.42. Hence, at 7 months infants discriminate the difference between native and nonnative contrasts with a preference for nonnative sounds, regardless of the degree of bilingual exposure (Figure 18).

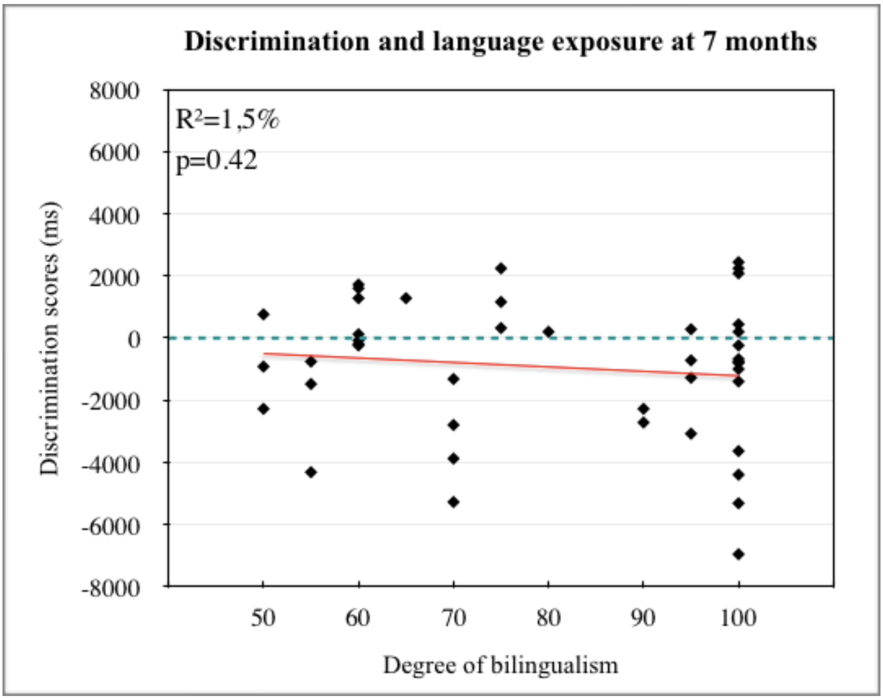

Figure 18. The scatterplot of 7-month-old infants shows the relation between the degree of bilingual exposure (percentage of amount of exposure to L1) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

At 12 months, the regression results revealed a tendency of an effect of the degree of bilingualism on discrimination, $F(1, 42)=3.37$, p=0.07, R^2=7.4% (see Figure 19). The trend suggested that more bilingual environments increased infants' discrimination with higher preference for the dental trials. In contrast, discrimination scores were closer to 0 the more monolingual infants' environment was.

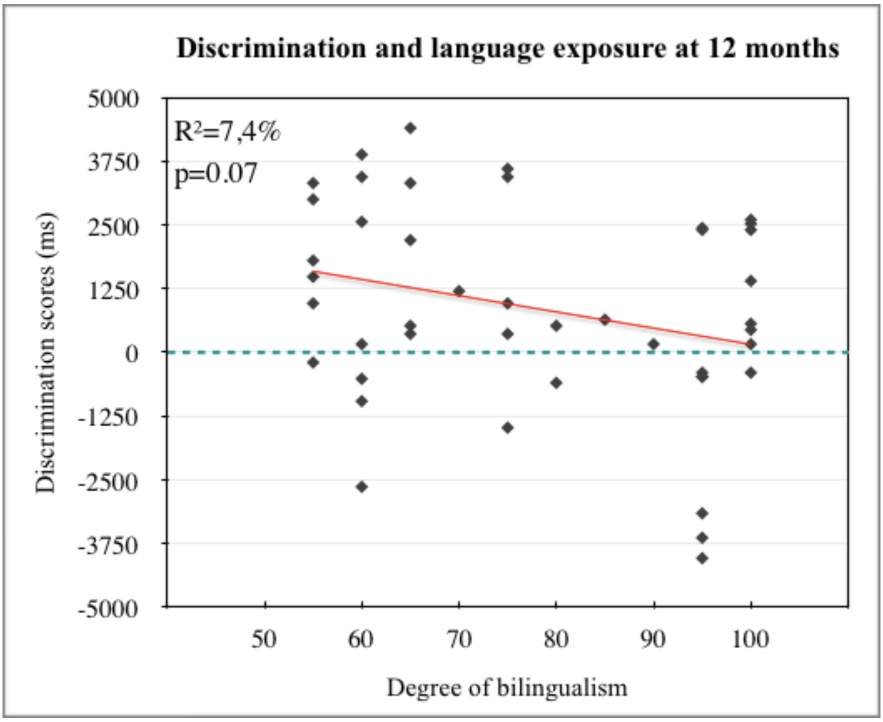

Figure 19. The scatterplot of 12-month-old infants shows the relation between the degree of bilingual exposure (percentage of amount of exposure to L1) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

However, these results did not reach significance. In order to determine whether specific language exposure effects were affecting the results we conducted a follow-up multifactorial regression analysis including the degree of language exposure to the previous analysis. We calculated specific language exposure on the basis of exposure to Spanish, with a range from 0% (monolingual Catalan) to 100% (monolingual Spanish), in order to control for language specific effects confounded with the variable bilingualism. In this case, the effect was even closer to reach significance $F(1, 41)=4.40$, $p=0.058$, R^2(adjusted)=13.7%.

Hence, although the effects of the degree of bilingualism were not significant at 12 months, the close to significance trend suggests that the degree of bilingualism may be influencing infants' responses more than at 7 months.

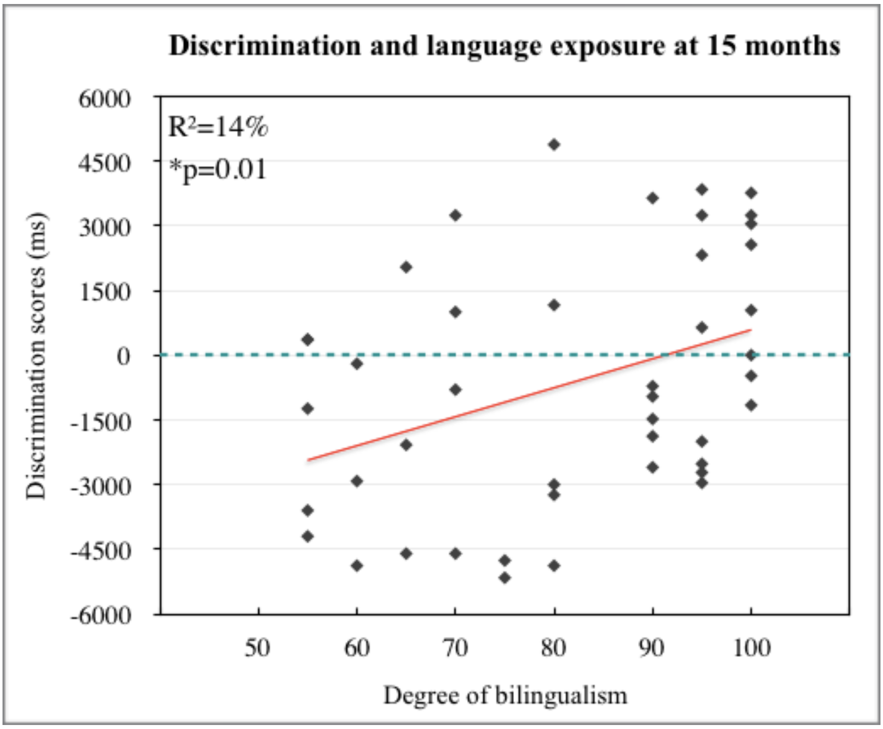

Figure 20. The scatterplot of 15-month-old infants shows the relation between the degree of bilingual exposure (percentage of amount of exposure to L1) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

Finally, the analysis with 15 month-old infants revealed an effect of the degree of bilingualism on discrimination, $F(1, 43)=6.82$, $p=0.01$, $R^2=14\%$. Hence, at 15 months, infants raised in more bilingual environments showed enhanced discrimination -with higher looking proportions to the nonnative trials- in comparison to infants raised in predominantly monolingual environments (see Figure 20).

3.2. Language specificity and discrimination

For the same reasons before mentioned regarding the characteristics of our samples, we could establish a second quantitative measure of language input with the percentage of exposure to each language. Despite that Catalan and Spanish share many linguistic similarities, two main differences arise at the phonetic level. First, the phonetic repertoire of Spanish is more reduced than the phonetic repertoire of Catalan. Spanish has 5 vowels and 19 consonants whereas Catalan has 8 vowels and 25 consonants (24 phonemes versus 33 phonemes, respectively). Second, Catalan has contrasts which are closer in the phonetic space in comparison to Spanish. As we have already discussed in the introduction, studies testing perception of vowels and consonants in bilingual adults and preschoolers show that the perceptual abilities of bilinguals differ according to their dominant language (Bosch et al., 1994; Pallier et al., 1997; Sebastián-Gallés & Soto-Faraco, 1999; Bosch, Costa, & Sebastián-Gallés, 2000; Ramon-Casas et al., 2009). The contrasts tested in such studies were the particular contrasts that are represented as one single phonetic category in Spanish and two phonetic categories in Catalan. In contrast, in our discrimination study, we test infants with a native dental unvoiced plosive, which is represented as a single category in both languages and, furthermore, the relative frequency of occurrence in each language is quite similar (Spanish /t/=4.52%, Catalan /t/=5.17%). The nonnative retroflex contrast is also equally absent in both languages' repertoires. Hence, we should not expect effects of frequency of occurrence of sounds according to infants' dominant language. Nonetheless, we could find language specificeffects driven by 3 other possible differences between languages.

Spanish phonetic

	Bilabial	Labiodental	Dental	Alveolar	Palatal	Velar
Plosive	p b		t d			k g
Affricate					t͡ʃ	
Nasal	m			n	ɲ	
Tap or flap				ɾ	j	
Trill				r		
Fricative		f	θ	s		x
Lateral approximant				l	ʎ	

Catalan phonetic repertoire

	bilabial	labiodental	dental	alveolar	postalveolar	palatal	velar
Plosive	p b		t d				k g
Affricate				t͡s d͡z	t͡ʃ d͡ʒ		
Fricative		f v		s z	ʃ ʒ		
Nasal	m	ɱ		n		ɲ	ŋ
Trill				r			
Flap				ɾ			
Lateral				l		ʎ	

Table 1. Phonetic repertoires of consonants of Spanish and Catalan.

3.2.1.1. Phoneme density in the phonological space

Catalan has 4 additional alveolar and post-alveolar affricate contrasts [tʃ], [dʒ], [ts] and [dz] whereas in Spanish there is only one [tʃ]. Hence, the higher density of contrasts closer to the dental plosive /t/ in the case of Catalan could drive differences in the timing of perceptual reorganization as a function of the amount of Catalan or Spanish input.

So far, if we compare the discrimination results of Spanish and Catalan monolingual infants to previous results in the literature with of English monolingual infants, we observe no differences regarding the timing of narrowing of the dental-retroflex contrast. However, our monolingual sample merges both Catalan and Spanish monolingual infants. Therefore, in case that the concentration of phonemes in the phonetic space plays a role in narrowing, our data should further be explored in terms of amount of exposure to each of the two languages. That is, the differences in the properties of the input between languages could predict differences in infants' discrimination abilities according to their predominant linguistic background. If the differences in phoneme distribution between languages predict differences in infants' discrimination abilities, then the language dominance in the case of bilingual infants could affect the process of phonetic acquisition. In the case that we find language-specific effects we should further disentangle that such effects are not driven by other confounded factors, such as the size of the linguistic repertoire or the complexity of the L2 in the case of bilinguals.

3.2.1.2. Size of the phonetic repertoire

If the size of the linguistic repertoire affects narrowing, we should expect cross-language differences in the offset of the narrowing period across languages. We would observe differences in the timing of narrowing between Spanish monolingual infants and the rest of the groups which are exposed to the larger phonetic repertoire of Catalan, such as Catalan monolingual infants and Catalan-Spanish bilingual infants (Costa, Cutler, & Sebastián-Gallés, 1998). Furthermore, previous data reported in the literature including English monolingual infants tested with the same contrast, would add another possible group to test this possibility, since English, with 20 vowels and 24 consonants, would represent the largest repertoire, in the opposite extreme compared to Spanish.

3.2.1.3. Complexity of L2 in comparison to L1

Taking into account the size and distribution of sounds in Catalan and Spanish, infants who are predominantly exposed to Catalan as L1 could acquire the fewer Spanish phonetic contrasts in L2 easier -regardless of the relatively reduced exposure to it- than infants predominantly exposed to Spanish as L1, who have to acquire the more complex phonetic repertoire of Catalan as L2 in the context of limited exposure. Therefore, if the complexity of the phonetic repertoire of a second language plays a role in phonetic narrowing, this prediction would imply a delay in the process of phonetic narrowing in the case of Spanish-dominant bilingual infants in comparison to Spanish monolinguals and Catalan-dominant infants.

3.2.2. Results

To address the above mentioned hypothesis, we analysed the samples of Experiment 1, Experiment 2 and Experiment 3 to determine whether language specificity affected discrimination of native-nonnative contrasts.

The degree of exposure was calculated on the basis of the percentage of exposure to Spanish (0% represents Catalan monolingual environments and 100% represents Spanish monolingual environments) and was used as the predicting continuous variable. The discrimination scores (difference between looking proportions to the Same and to the Switch trials) were set as the dependent variable.

At 7 months, the regression analysis performed to determine the influence of each language on infants' discrimination responses emerged as significant (R^2=8.8%, $F(1, 42)=4.03$, p=.05). That is, the higher the exposure to Catalan was the more infants discriminated in the direction of the nonnative trial, and the higher the exposure to Spanish was the lesser discrimination between contrasts was observed (see Figure 21).

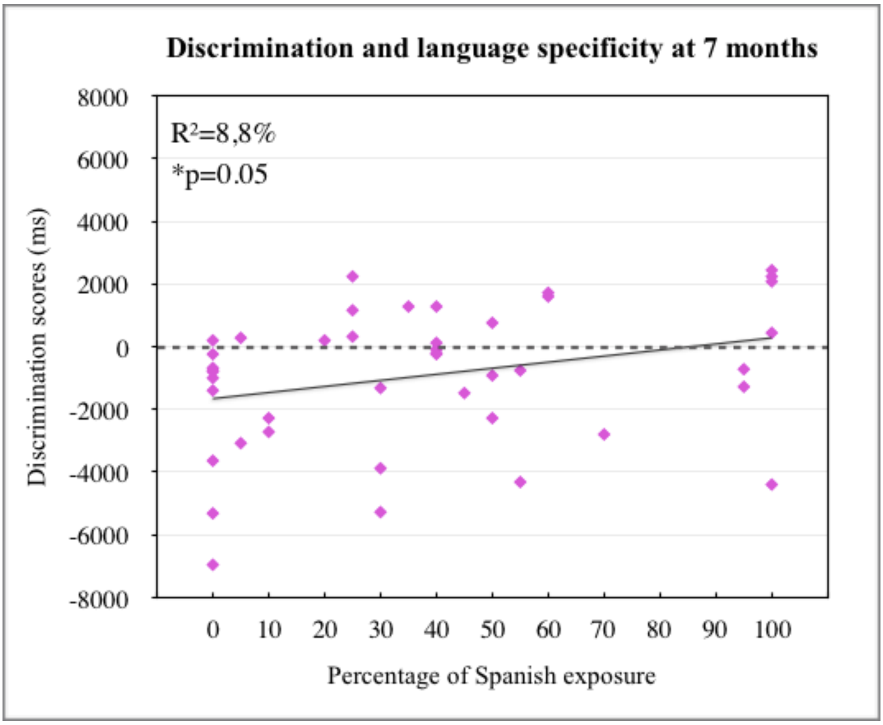

Figure 21. The scatterplot of 7-month-old infants shows the relation between the relative amount of language exposure (percentage of amount of exposure to Spanish) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

Also at 12 months the regression analysis performed to disentangle if language dominance influenced infants' discrimination responses emerged as significant. Our results, depicted in Figure 22, confirmed that the percentage of exposure to Spanish predicted infants' discrimination scores at 12 months (R^2=10.1%, $F(1, 42)=4.71$, p=.04). Nonetheless, and in contrast with the pattern observed with 7 month-old infants, at 12 months a higher exposure to Catalan correlated with lower discrimination values, whereas a higher exposure to Spanish correlated with longer looks to the native trials.

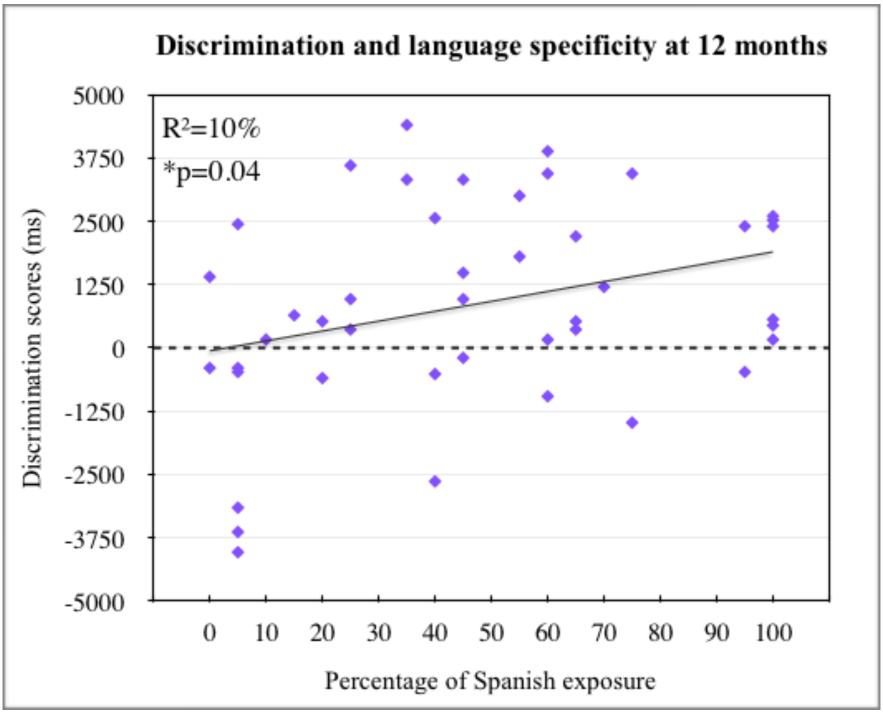

Figure 22. The scatterplot of 12-month-old infants shows the relation between the relative amount of language exposure (percentage of amount of exposure to Spanish) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

Importantly, at 15 months, precisely the age when the degree of bilingualism predicts discrimination scores, there were no effects of language dominance on infants' discrimination abilities (R^2=.1%, $F(1, 42)$=0.04, p=.85). Results are shown in Figure 23.

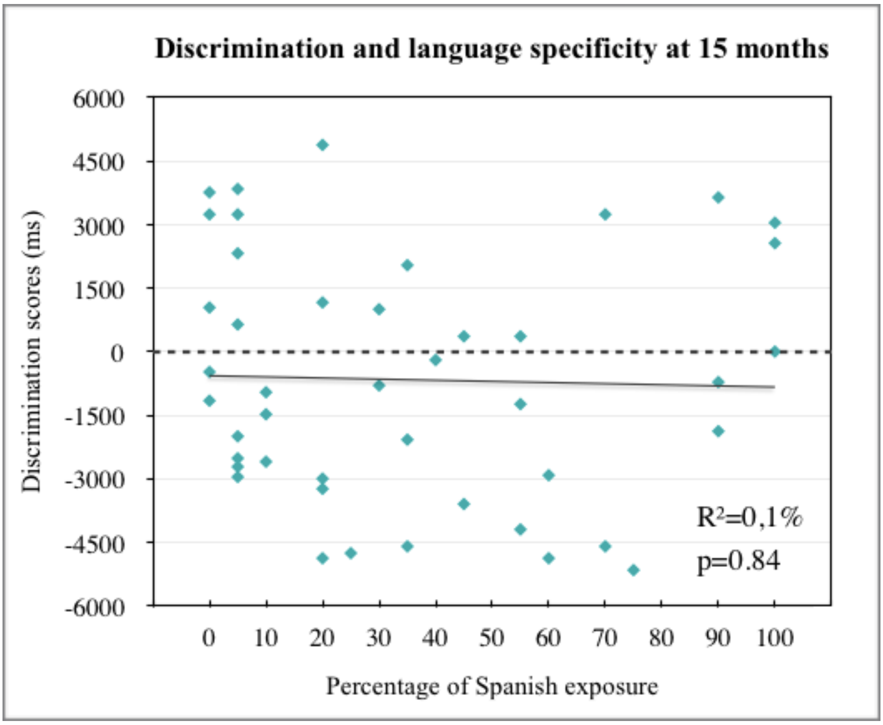

Figure 23. The scatterplot of 15-month-old infants shows the relation between the relative amount of language exposure (percentage of amount of exposure to Spanish) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials).

3.3. Chapter discussion

In the previous chapter we found differences in discrimination between monolingual and bilingual infants at 12 and 15 months. In this chapter we examined in detail the effects of the linguistic input on infants' perception.

First, we explored whether the gradual exposure from one to two languages predicts infants' discrimination responses. As expected from the findings of the previous chapter, our results with the 7-month-old group showed that the degree of bilingualism did not influence infants' ability to discriminate nonnative consonants at such early stage. At 12 months, there was a marginal effect of the degree of bilingualism on discrimination although, only at 15 months, the degree of bilingual exposure predicted infants' discrimination responses. Hence, we can conclude that throughout development the degree of bilingualism gradually becomes more decisive at predicting the differences in discrimination.

Second, we also found an effect of specific language exposure on discrimination at 7 and at 12 months. Higher exposures to Catalan paralleled the results observed in English monolingual infants of previous research studies (Werker et al., 1984; Anderson et al., 2003), suggesting an initial sensitivity for nonnative contrasts which is lost by 12 months. Conversely, higher exposures to Spanish showed different outcomes. At 7 months, a higher exposure to Spanish correlated with reduced discrimination and at 12 months with increased discrimination. Thus, at 12 months infants raised in Spanish dominant environments show increased sensitivity in comparison to infants raised in Catalan-dominant environments.

Such results could be driven by the differences in phonetic properties between the Catalan and Spanish language. In the introduction we addressed the main factors that could be explaining the language dominance effects. We discarded an effect of exposure to the native unvoiced dental plosive /t/ category, since its frequency of occurrence is very similar in both languages. Now we can also discard the difficulty of exposure to L2 as a predictor of discrimination, since Spanish monolingual infants showed the same pattern of discrimination than Spanish-dominant bilinguals.

Therefore, only two of the previously posited arguments remain as possible explanations for the language specificity effects, the size of the phonological repertoire and phoneme density. Regarding the size of the phonological repertoire, Catalan -as well as English- has a larger phonetic repertories than Spanish. Hence, if the size of the phonetic repertoire is accounting for the language specificity effects observed in discrimination, from our results we should conclude that larger phonetic repertoires are narrowed earlier than more reduced phonetic repertoires. Thus, according to this possibility, larger phonetic repertoires could facilitate earlier narrowing. In the adult literature, cross-language comparisons with monolingual populations have suggested that the size of phonological repertoires correlate with phoneme identification. A study including Spanish, Dutch, Polish, English and Catalan showed that smaller sizes of vowels and consonants in the repertoire correlated with longer reaction times in phoneme identification tasks (Wagner et al., 2008). Surprisingly, in their study, the results with the Catalan language did not match the trend, since Catalan subjects responded faster regardless of the comparative size of their phonological repertoire. However, the Catalan participants of their study were faculty students recruited in Barcelona, which suggests that the participants in the Catalan group, in contrast with the other language groups, were bilingual. Hence, given the far-fetched predictions we can drive from our regression analysis, and considering that the distributions of Catalan and Spanish monolingual infants were not equated within our monolingual groups, further studies would be needed to properly test the phonetic repertoire size hypothesis with infants.

Finally, and more plausibly, we proposed the argument of phoneme density to account for differences in discrimination. The Catalan language -and also English- has 4 additional alveolar and post-alveolar affricate contrasts [tʃ], [dʒ], [ts] and [dz] whereas in Spanish there is only one category [tʃ] occupying the equivalent phonetic space. Hence, the higher density of contrasts closer to the dental plosive /t/, present in Catalan and English, could be accounting for the earlier timing of perceptual reorganization of the dental-retroflex distinction for such two populations in comparison with Spanish populations. Thus, higher phoneme density may facilitate the process of phonetic convergence.

In conclusion, from this chapter we can summarize that the degree of bilingual exposure predicts the size of the effects in discrimination at 15 months, and that at earlier developmental stages, at 7 and 12 months, the specific characteristics of language predict discrimination scores. Thus, the type and the amount of language exposure influence perceptual reorganization at different stages in development.

4. PHONETIC PERCEPTION AND PRODUCTION: INSIGHTS FROM THE DEVELOPMENT OF BILINGUAL INFANTS

4.1. Introduction

4.1.1. The biological constraints of babbling

The universal regularities in the sequence of phonemic acquisition (D K Oller, 1980) and the restricted repertoire of phonemes in early speech and babble suggest that infants have a biological predisposition for certain articulatory dynamics, regardless of their linguistic background, and that they are functionally incapable of producing sounds which are articulated later in development (Locke, 1985; Piske, 1997). Oller and colleagues (1980) reported 4 phases in the development of speech-like vocal development before the production of the first words. The 'phonation stage', within the first two months of age, in which infants' produce quasi-vowels, the precursors of native vowel productions. At 2 to 3 months the 'gooing phase' follows, adding the articulation of sounds in the back of the vocal cavity, which have been suggested to be the precursors of consonant productions. The first syllabic productions, also known as marginal babbling, can be observed from 4 to 6 months, during the 'expansion stage'. The 'canonical stage' follows from 7 to 10 months, with reduplicated syllabic productions and well-formed syllables. As previously shown, this canonical stage is precisely when the shift between language general to language specific changes occur in speech perception.

4.1.2. Experience modulates infants' speech productions

Infants' attunement to the properties of their linguistic environment can be observed not only throughout the changes in phonetic discrimination during their first months of life but also in the developmental changes of their speech productions within the same period. Young children and adults differ in the degree of syllabic articulation (Nittrouer, Studdert-Kennedy, & McGowan, 1989). As a product of changes in musculoskeletal growth and neuromotor development, infants' initial speech movements cam become increasingly similar to the ones of adults (Kent, 1984; Kent & Vorperian, 1995; Smith, Goffman, & Stark, 1995). However, despite the universality in the development of infants' productions, the characteristics of their utterances depend on their specific linguistic experience from very early stages in development. In line with the studies in language discrimination, newborns cries also differ depending on which language they are exposed to in the womb (Mampe, Friederici, Christophe, & Wermke, 2009). Mampe and colleagues (2009) evaluated the intensity and melodic contour of French and German infants and the comparisons between the two groups showed that French infants produced cries with rising melody contours while, in contrast, German infants produced cries with falling contours. Such results suggest that the prosody of infants' linguistic environment influence infants' first production abilities even before birth.

Also, differences in babbling between hearing and deaf infants at 10 months of age show a poorer performance in productions in the case deaf infants, indicating a strong connection between infants' perceptual abilities and the performance of productions of the language of their environment (Oller & Eilers, 1988).

Multiple cross-linguistic studies and other studies that correlate phoneme frequency and infants' type of productions reveal that, beyond the initial commonalities across infants' productions, infants' utterances also imitate native language patterns (Best, 1999; Boysson-Bardies & Vihman, 1991; Kuhl & Meltzoff, 1988; Vihman, 1993).

Nonetheless, up to date the results obtained from the development of babbling in bilingual infants suggest that the differences in the input are neither correlated with infants' production development nor with proficiency. Oller & Eilers (1997) conducted a study to compare the productions of monolingual and bilingual infants between 4 and 18 months. The results found that the ages of onset for canonical babbling and the accuracy in their productions of syllables and vowel sounds were equivalent. Their conclusions suggested that the biological development of speech is not altered by modifications in the frequency of linguistic input.

4.1.3. The relevance of consonant productions

Production of consonants has been considered important for its diversity and increased frequency at the later lexical stage. Stoel-Gammon & Otomo (1986) found that hearing-impared infants produced lesser consonants than hearing infants between 4 and 11 months. Their results showed that hearing impairment influences consonant productions already by 6 months. Other studies have shown that consonant vocalizations in both babble and first words at 12 months predict greater phonological advance at 3 years of age (Vihman & Greenlee, 1987). The number of specific consonants produced consistently between 9 and 16 months predicts referential lexical use at 16 months, which at the same time correlates with the onset of a sharp increase in the number of different words produced by infants (McCune & Vihman, 2001). Also, a secondary finding in the study by Werker et al. (2002) found that infants who score higher in the production portion of the Child Development Inventory (CDI) have larger production vocabularies at 14, 17 and 20 months each age are better at labeling minimal pairs to objects. Hence, infants who produce more words within their age range are also better able to learn minimal different words at the phonetic level.

4.1.4. Correlation between perception and production

The classic views correlating perception and production in infants suggest an unidirectional influence of perception over production (Kent, 1984; Oller & Eilers, 1988). However, literature with adults suggests that such link is bidirectional. Besides the relevant areas for language perception, motor areas are also active when adults listen to speech (D'Ausilio et al., 2009; D'Ausilio et al., 2012; Fadiga & Craighero, 2002; Möttönen & Watkins, 2009; Pulvermüller & Huss, 2006; Wilson, Saygın, & Sereno, 2004).

The finding that infants' first words are relatively accurate and closely related to their babbling patterns (Ferguson & Farwell, 1975; Vihman, Macken, Miller, Simmons, & Miller, 1985). Some authors have interpreted such facts as evidence that infants select the first words to say on the basis of how pronounceable they are (Vihman, 1991). The articulatory filter hypothesis (Boysson-Bardies & Vihman, 1991; Vihman, 1991) suggests that consonants regularly produced in babbling boost the perceptual saliency of both adult and own speech sounds. According to such 'output as input' or 'articulatory filter' theory, the familiarity of infants' own sounds enhances their perception of -exclusively- the same sounds in their acoustic environment (Elbers, 1997).

Recent studies about the correlation between infants' perception and production of consonants support this theoretical approach. According to DePaolis, Vihman, & Keren-Portnoy (2011), infants who can only produce one consonant prefer to attend to that consonant more than to other consonants. Conversely, infants who can produce two or more consonants prefer to attend to novel sounds that are not present in their productive repertoire, showing a developmental shift from a familiarity to a novelty preference. Depaolis et al. (2013) recorded infants' utterances bimonthly from birth until 12 months. By 12.5 months, infants were tested on discrimination of equally frequent native consonants in their input. Their results with this different methodology confirmed that the more the infants practice a consonant the less that particular consonant holds their attention. Moreover, such attentional patterns to sounds and their productions at 6 months, both correlate with the size of their expressive lexicon at 12 months and 18 months (Majorano, Vihman, & DePaolis, 2014).

Recent findings found by Bruderer et al. (2015) are in line with this hypothesis. They tested 3 different groups of 6-month-old infants with the classic dental-retroflex contrasts discrimination task. Two groups were put a teething toy in their mouth. For one group, the toy impaired the tip of the tongue movement needed to produce their native sound. For the other group, the toy did not affect the tongue movement. A third control group used no toy in the discrimination experiment. Their results demonstrated that only in the case in which infants tongue movement is restricted, infants cease to show signs of discrimination. Therefore, an impairment of the oral-motor movements implicated in the production of a specific native category impairs infants' perception of the close nonnative distinction.

4.1.5. Perception and production in bilingual infants

During the course of testing infants in consonant discrimination, we observed that many infants were producing utterances during the task. Moreover, differences in production between monolingual and bilingual infants were strikingly notable at some ages. Hence, we decided to conduct a post-hoc analysis of infants' productions throughout development to search for possible correlations with the results in perception. All the videos of the infants that were included in the analysis of the discrimination studies were analyzed by an external coder to obtain information about how much each language group babbled at each age, which type of utterances infants perform across development and how accurate they are at producing their native consonants. The preliminary results we obtained are reported in the current chapter.

4.2. Babbling behavior

4.2.1. Spontaneous babbling

The sample submitted for analysis were all the infants who were tested in Experiment 1, Experiment 2 and Experiment 3.

We compared the proportion of infants who produced sounds from the ones who remained silent during the experimental session across language groups. We conducted a chi-square analysis to determine whether language (language group: monolingual vs bilingual environment) correlated with infants' production behavior (1=speak, 0=silent). See Table 2 and Table 3 for detailed numbers.

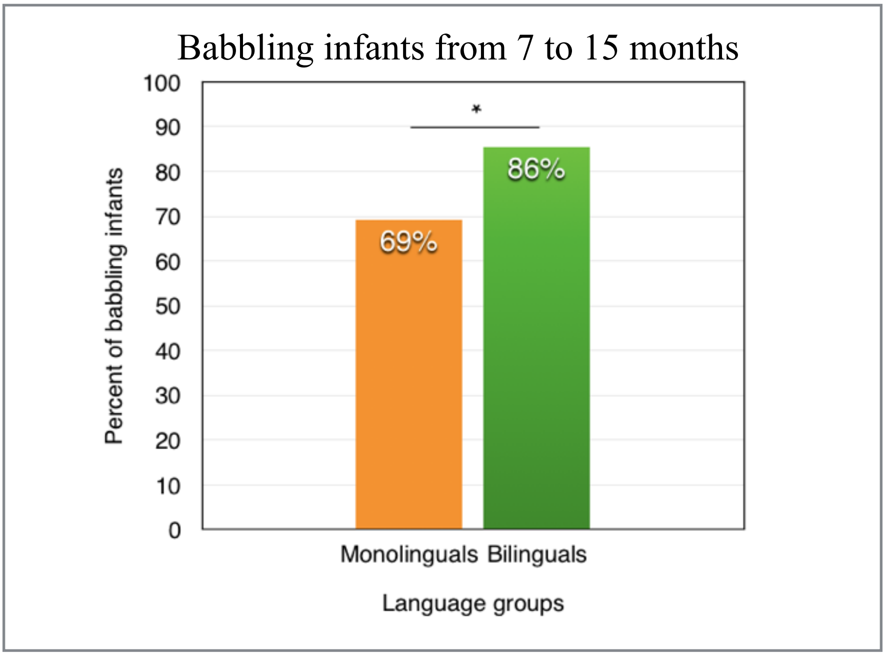

Figure 22. Percentage of monolingual and bilingual infants who babbled during the infant visual habituation task in Experiment 1, 2 and 3.

The results revealed an effect of language exposure on babbling ($X^2(1, 131) = 4.94$, $p<.026$). That is, accounting for the infants who participated in all three experiments, more bilingual infants (86%) than monolingual infants (69%) produced sounds (see Figure 24). There was no main effect of age group.

In order to further explore the language effect at each developmental stage, additional regression analysis were performed with each age group. Both at 7 months and at 15 months the effect of language exposure over babbling emerged ($X^2(1, 44) = 5.35$, $p=.021$, and ($X^2(1, 44) = 4.24$, $p=.039$) respectively. At 7 months more bilingual infants (86%) than monolingual infants (55%) produced utterances. In parallel, at 15 months more bilingual infants (95%) than monolingual infants (73%) produced utterances. Figure 25

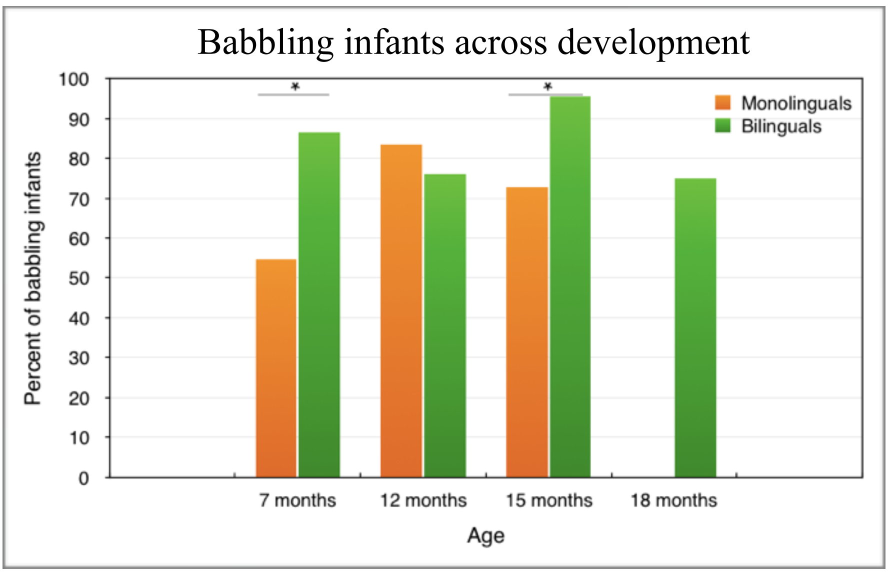

Figure 25. Percentage of monolingual and bilingual infants who babbled during the visual habituation task in each experiment.

shows the percentage of speaking infants in all the experiments by language and age of test (an additional 18 month-old group is plotted in the graph for supply of additional information, despite it could not be included in the analysis).

In order to observe the effect of age over infants' production behavior in each particular linguistic environment, we conducted two additional regression analysis with each language group, including age (continuous variable accounting for days since birth) as a predictor variable and amount of babbling infants as the dependent variable. There was no effect of age over the number of babbling infants for neither of the two language groups.

Production in monolingual infants

MONOLINGUAL INFANTS	Babbling	Silent	Total sample	Percentage babbling infants
7 months	12	10	22	55%
12 months	15	3	18	83%
15 months	16	6	22	73%
Total	43	19	62	**69%**

Table 2. The table depicts the absolute number of babbling and silent monolingual participants, the total number of monolinguals in each study and the percentage of babbling monolingual infants in each experiment sample who produced sounds during the infants habituation task.

Production in bilingual infants				
BILINGUAL INFANTS	Babbling	Silent	Total sample	Percentage babbling infants
7 months	19	3	22	86%
12 months	19	6	25	76%
15 months	21	1	22	95%
18 months	15	5	20	75%
Total (including 18 months)	74	15	89	83%
Total	59	10	69	**86%**

Table 3. The table depicts the absolute number of babbling and silent bilingual participants, the total number of bilinguals in each study and the percentage of babbling bilingual infants in each experiment sample who produced sounds during the infants habituation task.

4.2.2. Non-native contrast discrimination and spontaneous productions

We compared the performance in discrimination of monolingual and bilingual infants according to whether infants produced utterances during the experiment or remained silent. The correlation between the number of babbling infants (babbling vs. silent: 1, 0) and discrimination scores, was significant ($r(129) = -0.196$, p=.03). The direction of the results suggest that infants who babbled during the discrimination task looked longer to the screen during the Switch trials and infants who remained silent looked longer during the Same trials (see Figure 26). A multiple regression analysis including the variable language background (monolingual vs.

bilingual: 1, 0) and babbling behavior (babbling vs. silent: 1, 0) revealed no effects driven by language group. Hence, we can conclude that the correlation between babbling and discrimination was not influenced by infants' linguistic background.

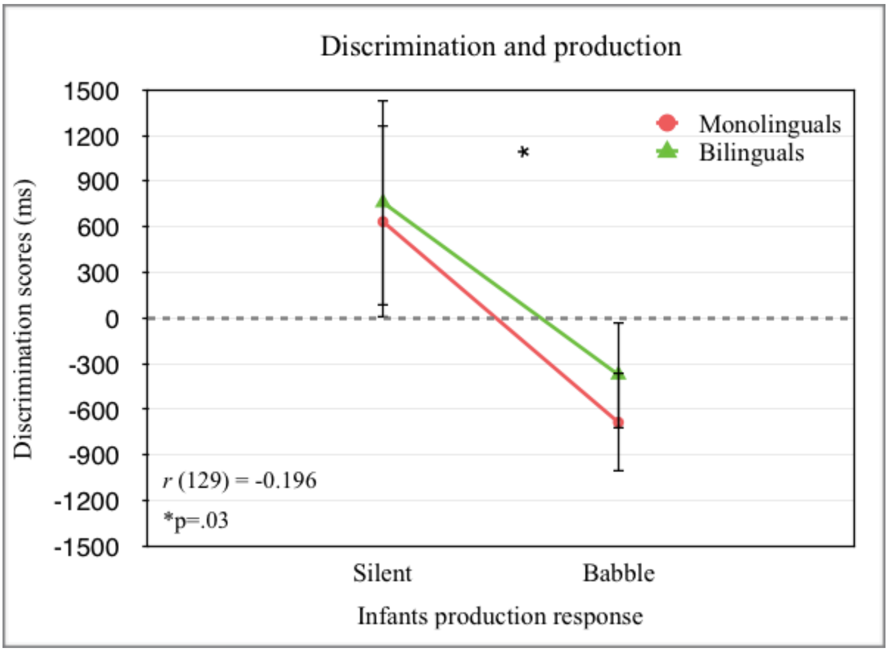

Figure 26. Relation between babbling behavior (infants who remained silent and infants who babbled during the visual habituation task) and discrimination scores (difference in milliseconds between SameTrials and SwitchTrials). Error bars represent standard errors.

4.3. Babbling patterns

4.3.1. Types of babbling and frequency of utterances

In order to determine whether monolingual and bilingual infants production patterns differed, we conducted several analysis comparing the number and the kind of utterances both groups performed across development. We divided the type of infants' productions into two different sound categories. The /ta/ productions which include */t/-like* sounds, were considered as imitative utterances of the sounds primed by the the discrimination task. The *other* utterances, which were not related to the sounds presented during the task, were considered a more general marker of babbling. The data analysis was performed with infants at 7, 12 and 15 months, and the number of productions for each type of utterance were analyzed separately (see Table 4 and Table 5 at the end of this section).

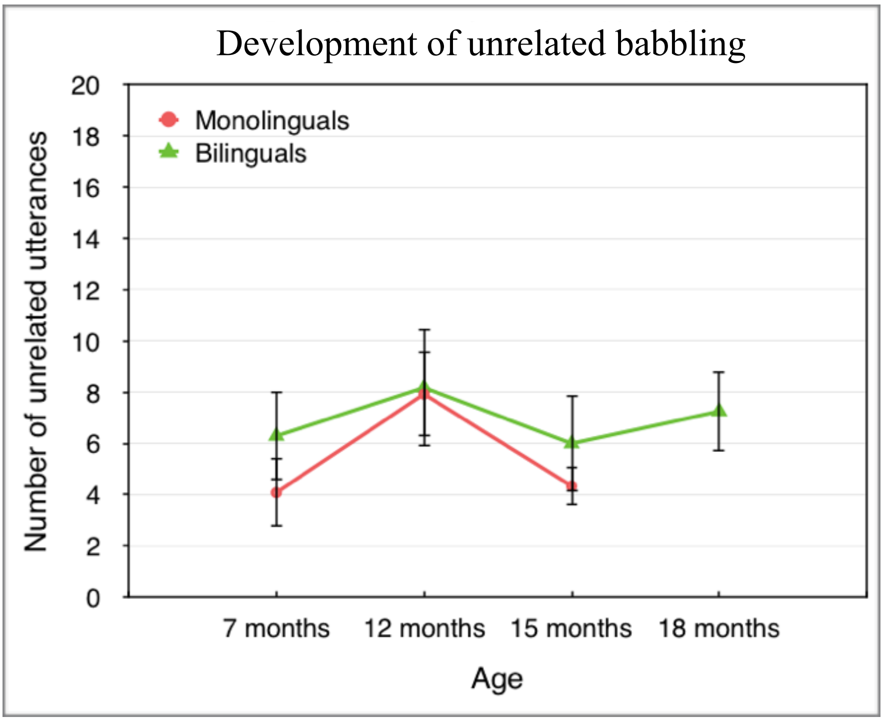

Figure 27. Mean number of 'unrelated utterances' in monolingual and bilingual infants by age in which the experiment was conducted. Error bars represent standard errors.

For each of the 'other utterances' condition, we conducted a 2 (language group: monolingual vs bilingual environment) x 3 (age: 7, 12 and 15 months) mixed model ANOVA, with number utterances to the test trials as the dependent variable. The results did not reveal main effects of language nor age, nor any interaction of experiments' age and language group (Figure 27). Since in the case of the number of /ta/ productions the sample of 7-month-old infants had only 2 subjects in total and, therefore, was not fairly comparable to the older age groups, for the 'imitative babbling' condition the 2 x 2 mixed model ANOVA was conducted only with

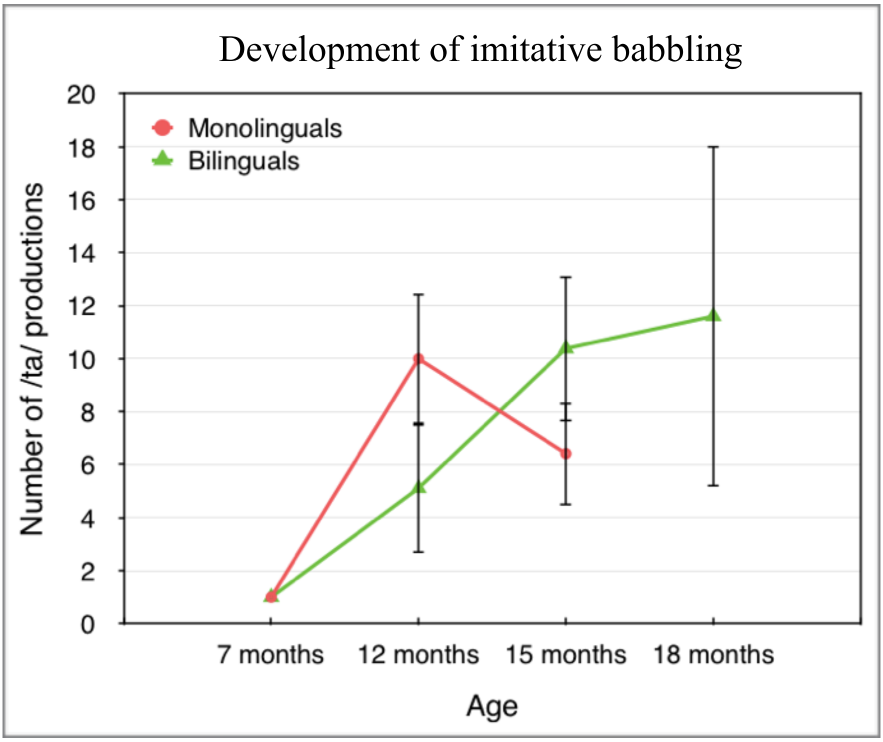

Figure 28. Mean number of 'imitative utterances' (repetition of /ta/ syllables) in monolingual and bilingual infants by age in which the experiment was conducted. Error bars represent standard errors.

the groups of 12 and 15 months of age (Figure 28). Again, the interaction of age by language did not reach significance. No main effects of language nor of experiment emerged. Additionally, we extracted a comparative measure to assess whether the proportion of /ta/ utterances with respect to the total number of utterances, either /ta/ or others, differed as a function of language groups or age. The proportions of productions are expressed in percentages in the corresponding Figure 29 (again, the data of the 7-month-old group and the 18-month-old group are presented in the graph despite it was not included in the analysis). The 2 (language group: monolingual vs bilingual environment) x 2 (age group: 12 and 15 months) mixed model ANOVA analysis did not reveal main effects nor interactions.

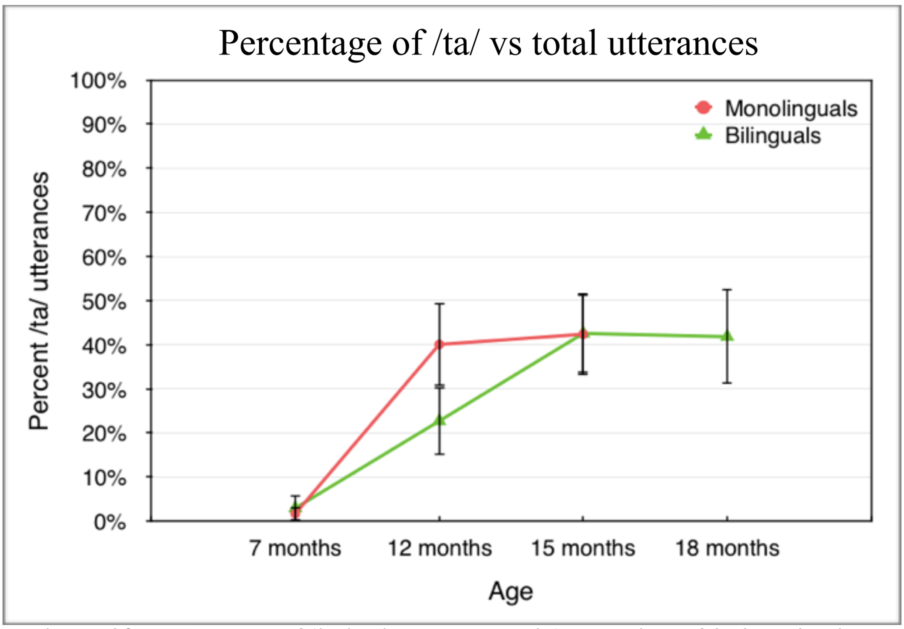

Figure 29. Percentage of 'imitative utterances' (proportion of /ta/ productions over the total number of utterances) in monolingual and bilingual infants by age in which the experiment was conducted. Error bars represent SEs.

Thus, from the series of analysis we conducted for the number and types of infants' productions we can conclude that there were no effects of language nor interactions between age and language for any of the three production measures.

Types of productions in monolingual infants					
MONO-LINGUAL INFANTS	Infants producing 'other'	Mean 'other' utterances	Infants producing [ta]	Mean [ta] utterances	Percent [ta] utterances vs total utterances
7 months	12	4,08	1	1	1,67%
12 months	13	7,92	10	10	40,05%
15 months	15	4,33	12	6,42	42,38%

Table 4. The table depicts the absolute number of monolingual subjects who produced 'unrelated utterances' (other than /ta/) and 'imitative productions' (/ta/ sounds), the means of each type of utterances per age and the percentage of imitative productions over the total number of productions.

Types of productions in bilingual infants					
BILINGUAL INFANTS	Infants producing 'other'	Mean 'other' utterances	Infants producing [ta]	Mean [ta] utterances	Percent [ta] utterances vs total utterances
7 months	17	6,29	1	1	2,94%
12 months	17	8,18	9	5,11	22,70%
15 months	18	6,00	13	10,38	42,55%
18 months	12	7,25	10	11,60	41,82%

Table 5. The chart depicts the absolute number of bilingual subjects who produced 'unrelated utterances' (other than /ta/) and 'imitative productions' (/ta/ sounds), the means of each type of utterances per age and the percentage of imitative productions over the total number of productions.

4.3.2. Degree of language/s exposure and production rates

A more detailed exploration taking into consideration the language variable as a continuum at each age, either on the basis of the degree of exposure to a monolingual-bilingual environment or on the basis of the degree of exposure to either Catalan or Spanish, allowed to further explore the relation between language perception and production.

First, we performed an analysis including the degree of bilingualism as a continuous variable to further explore the patterns of /ta/ productions observed in the previous section. The regression analysis confirmed the previous results. That is, when all groups of age were taken into account, the degree of bilingualism did not influence the number of absolute /ta/ productions or the proportion of /ta/ productions. Additionally, we conducted simple linear regression analysis separately for each group of age, to determine whether the amount of bilingual exposure an impact on the number of /ta/ utterances only at specific stages in development. The analysis included the degree of bilingualism as a predictor and the number of */ta/-like* utterances as a dependent variable. As shown in Figure 30, only at 12 months (N=19) was the regression analysis, found to be significant ($F(1, 17)=4.45$, $p=.05$, $R^2=20.7$). Thus, at 12 months, the more monolingual the environment was, the more /ta/ utterances were produced. Hence, the previous section analysis, conducted with the categorical division between monolingual and bilingual infants, was not sensitive enough as to detect the differences in infants' productions driven by differences in linguistic exposure.

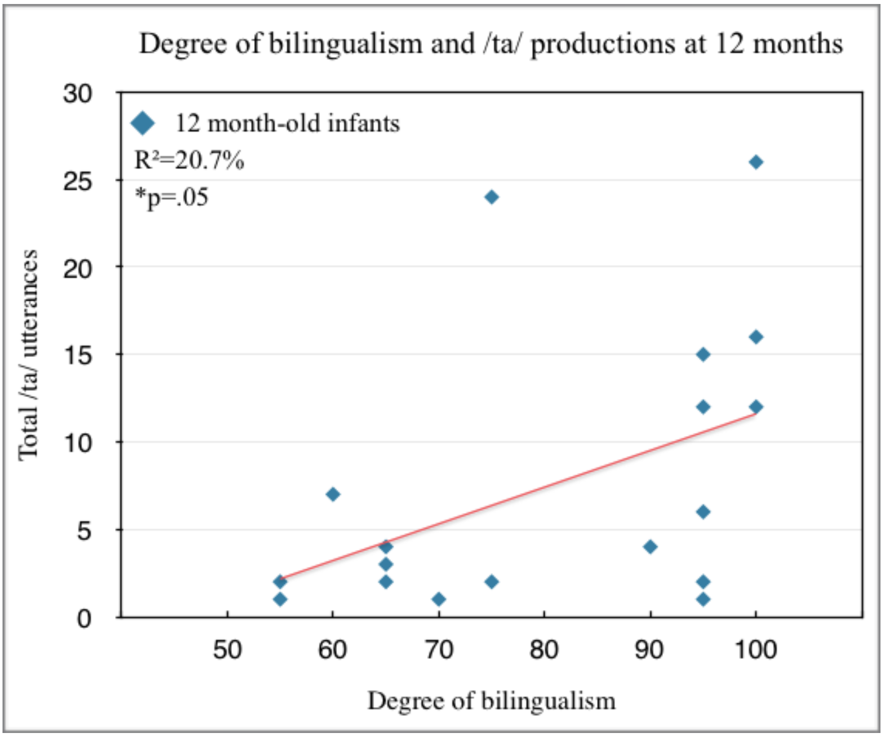

Figure 30. The scatterplot of 12-month-old infants shows the relation between the degree of bilingualism (percentage of exposure to L1) and the total number of imitative /ta/ utterances performed by each subject.

A second simple regression analysis including all infants who produced the syllable /ta/ (N=46) was conducted on the basis of the amount of exposure to Spanish. Results showed that the language dominance factor influenced the absolute number of /ta/ productions, (R^2=17%, $F(1, 44)=8.99$, p=.005). However, when the previous analysis was conducted with the relative measure of /ta/ productions (proportion of /ta/ utterances with respect to the total number of productions) no significant correlations emerged. In conclusion, two different effects of infants' language input on their number of productions emerged. First, only at 12 months did the degree of bilingual exposure predict the number of productions. Thus, monolingual exposure facilitates imitative babbling at 12 months. Second, when we took into account all the infants who performed imitative utterances across experiments, we found a language-specific effect of Spanish exposure over imitative utterances (see Figure 31). That is, infants with higher exposure to

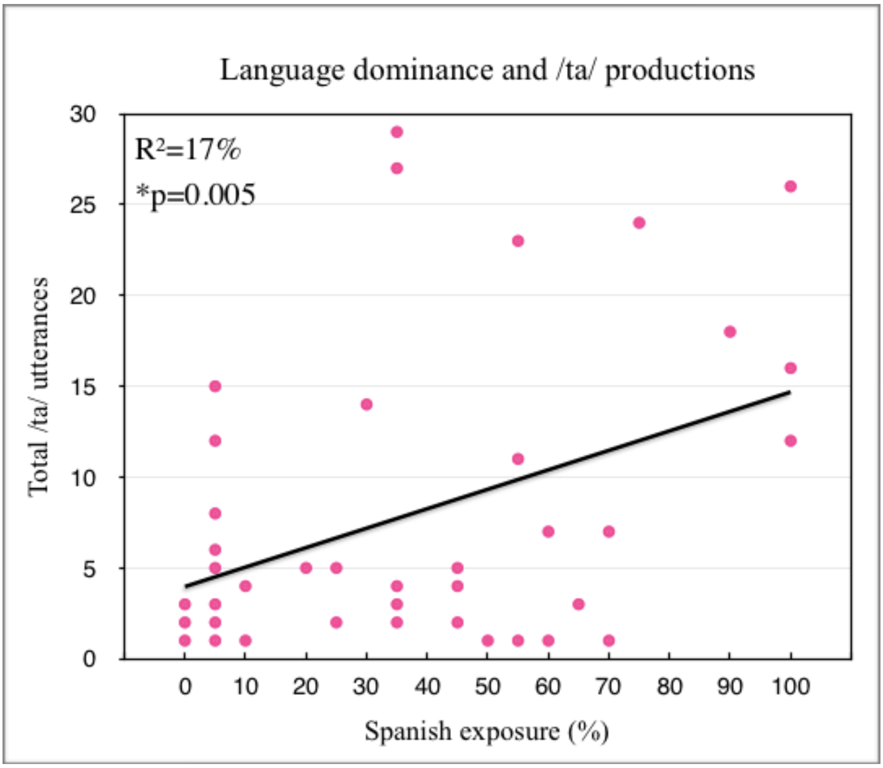

Figure 31. The scatterplot includes all the infants who produced /ta/ utterances and shows the relation between the amount of language exposure (percentage of exposure to Spanish) and the total number of imitative /ta/ utterances performed by each subject.

Spanish produced more imitative utterances than infants with higher exposure to Catalan.

4.3.3. Non-native contrast discrimination and production frequency

In order to assess whether discrimination and production were related, we explored the correlation between infants' discrimination scores and their productions using three different production measures: unrelated utterances, /ta/ utterances and proportion of /ta/ utterances with respect to the total number of production episodes. Neither the total number of 'other' utterances nor the total number

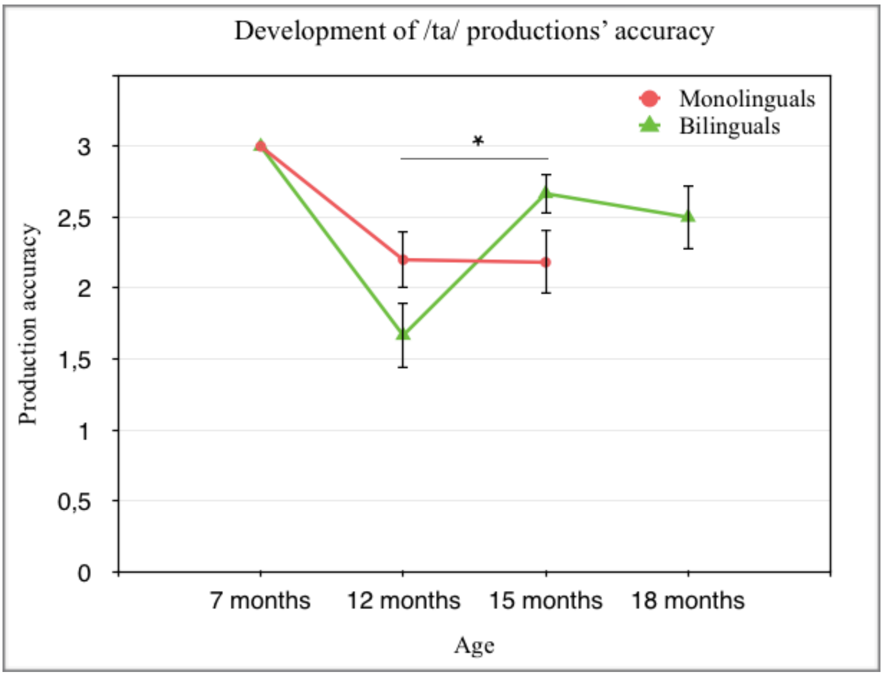

Figure 34. Relation between the means of production accuracy (ratings from values 1, 2, 3) and the age in which the experiment was conducted for monolingual and bilingual groups. Error bars represent standard errors.

of /ta/ utterances correlated with the infants' discrimination performance. Although the correlations of the proportion of /ta/ productions was not significant either, an additional correlation including all the infants who participated in the discrimination study, including the additional 18 month-old infants group (N=56), did show effects (see Figure 32). Hence, when accounting for all infants who produced /ta/ utterances between 7 and 18 months, higher proportions of imitative productions correlated with longer looks during the Switch trials ($r(54)= -0.288$, p=.03).

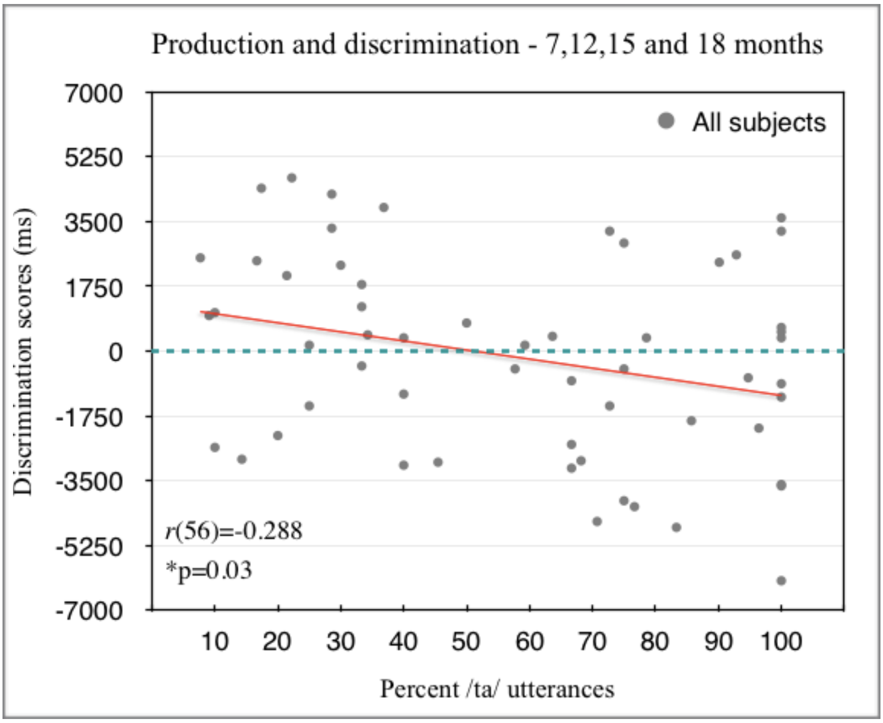

Figure 32. The scatterplot includes all the infants who produced /ta/ utterances in the 4 experiments. The graph shows the relation between the percentage of 'imitative utterances' (proportion of /ta/ utterances over the total of productions) and discrimination scores (difference in looking proportions between the Same and Switch trials expressed in milliseconds).

We conducted separate analysis for each of the two language groups, with infants between between 7 and 15 months, to explore the relationship between the three production variables and discrimination. For the group of monolingual producers no correlations emerged. As for the group of bilingual producers (see Figure 33), we found a significant correlation between the total number of /ta/ productions and their preference to listen to the nonnative sounds ($r(21) = -0.196$, p=.02).

In line with the previous general results for proportions of imitative babbling, bilingual infants who produced more /ta/ sounds also

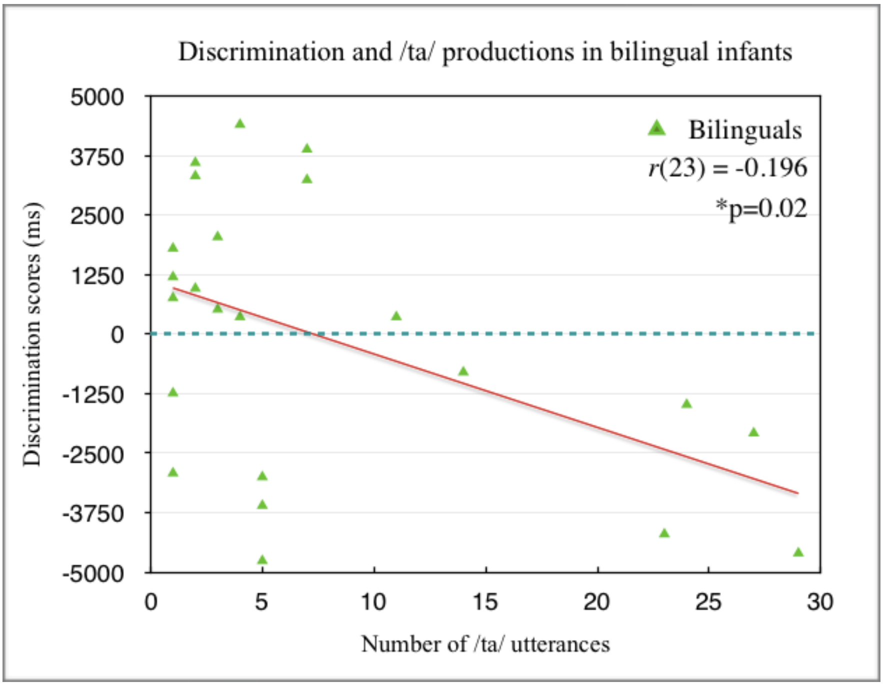

Figure 33. The scatterplot includes only bilingual infants who produced /ta/ utterances at 7, 12 and 15 months. The graph shows the relation between the number of 'imitative utterances' (repetitions of /ta/ utterances) and discrimination scores (difference in looking proportions between the Same and Switch trials expressed in milliseconds).

preferred to listen to the nonnative sounds in test. These results show that there may be a relation between babbling with nonnative contrast preference.

Since we also found that the rates of imitative babbling increased as a function of Spanish exposure, we also explored if only including Spanish monolingual infants imitative babbling and discrimination were correlated. The simple regression analysis conducted with

Spanish monolingual infants revealed no correlation between production and discrimination $r(19) = -0.197$, $p=.39$. Thus, when assessing for the influence of specific language exposure over infants' imitative utterances at all ages, our results revealed that a higher exposure to Spanish correlated with higher imitative babbling rates regardless of the age of testing. However, separate analysis with Spanish monolingual infants revealed no correlation between babbling and discrimination for this group.

4.4. Production accuracy

4.4.1. Accuracy of dental consonants' productions

In order to obtain a measure of production accuracy, the ratings of the /ta/ productions were graded from poor to good (1 to 3 respectively) by a native Spanish-Catalan speaker. Again, the 3 age groups and the 2 language groups were included for analysis (see Table 6 and Table 7 at the end of this section).

To address the question of whether infants linguistic background influenced the accuracy of their productions, we conducted a 2 (language group: monolinguals vs. bilinguals) x 2 (age groups: 12 months vs 15 months) mixed model ANOVA, with production accuracy (1, 2, 3) as the dependent variable. Since there were two data points in the 7-month-olds group of age, the analysis were conducted including only with the 12 and 15 month-old samples. There was a main effect of age ($M_{12months}$ = 1.9, SE = .16, $M_{15months}$= 2.43, SE=.14, $F(1, 38)=5.98$, p=.02). The age by language interaction also reached significance, $M_{12months*Mon}$= 2.2, SE = .2, $M_{12months*Bil}$ = 1.6, SE = .23, $M_{15months*Mon}$ = 2.2, SE=.22, $M_{15months*Bil}$ = 2.7, SE=.14; $F(1, 38)=6.43$, p=.016 (see Figure 34).

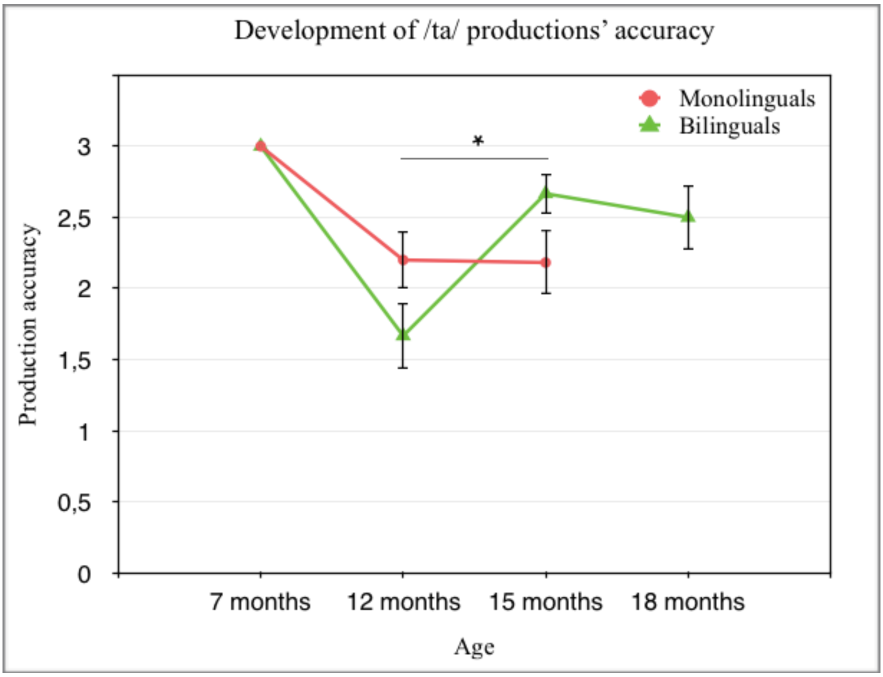

Figure 34. Relation between the means of production accuracy (ratings from values 1, 2, 3) and the age in which the experiment was conducted for monolingual and bilingual groups. Error bars represent standard errors.

Scheffe post-hoc comparisons revealed only one significant result. The accuracy of bilingual infants at 12 and 15 months differed. There was an improvement in their production accuracy between 12 and 15 months ($M_{Bil*15months-12months}$=1, SE=.29, p=0.001). Hence, we can conclude that monolingual infants maintained the accuracy of their /ta/ productions from 12 to 15 months while bilinguals significantly improved the quality of their productions from 12 months to 15 months.

Since these set of results resemble the results obtained in the discrimination studies, we further explored whether the accuracy and discrimination tendencies were correlated.

Production accuracy in monolingual infants			
MONOLINGUAL INFANTS	Good producers	Poor producers	Total number of infants producing /ta/
7 months	1	0	1
12 months	3	7	10
15 months	4	8	12
Total	8	15	23

Table 6. The chart depicts the total number of monolingual infants classified as good producers (infants who were rated with a 3 in /ta/ production accuracy) or poor producers (infants whose ratings were 1 or 2) and the total number of subjects who performed imitative babbling.

Production accuracy in bilingual infants			
BILINGUAL INFANTS	Good producers	Poor producers	Total number of infants producing /ta/
7 months	1	0	1
12 months	1	8	9
15 months	8	5	13
Total	10	13	23

Table 7. The table shows the total number of bilingual infants classified as good producers (infants who were rated with a 3 in /ta/ production accuracy) or poor producers (infants whose ratings were 1 or 2) and the total number of subjects who performed imitative babbling.

4.4.2. Non-native contrast discrimination and production accuracy

We explored whether the differences in the accuracy of /ta/ productions between language groups were related with the dental-retroflex contrast discrimination.

Infants' discrimination scores were analyzed with a 2 x 3 mixed model ANOVA including the factors language group (bilinguals vs monolinguals) and /ta/ production performance (1, 2, 3) as independent variables and discrimination scores as the dependent variable. The results revealed no effects nor interactions.

Nonetheless, since the babbling infants were not equally distributed across the accuracy performance conditions, an additional analysis was performed turning the quantitative accuracy variable into categorical. Thus, we grouped the good producers who uttered native-like productions (including /ta/ accuracy ratings of 3) and we compared them against the poor producers (with /ta/ accuracy ratings of 1 and 2). A 2 (monolinguals vs bilinguals) x 2 (good vs poor producers) mixed model ANOVA with the discrimination scores as the dependent variable revealed an interaction between the accuracy performance and language on discrimination ($M_{Good*Mon}$= 0.28 s, SE = 0.58, $M_{Poor*Mon}$ = -1.13 s, SE = 0.61, $M_{Good*Bil}$ = -1.17 s, SE = 0.87, $M_{Poor*Bil}$ = 1.03 s, SE = 0.77, $F(1, 40)=5.97$, p=.02). Follow up Scheffe post-hoc comparisons revealed two significant results. First, a difference in discrimination between poor perceivers between language groups was found, ($M_{PoorMon*PoorBils}$=-2.1 s, SE=9.45, p=0.03).

The results suggested that monolingual poor producers preferred to listen to the nonnative sounds while bilingual poor producers preferred to listen to the native sounds (see Figure 35). Second, whereas poor and good monolingual producers did not show differences in discrimination, a difference between the good and poor producers in the bilingual group emerged ($M_{GoodBil*PoorBils}$=2.21 s, SE=1.03, p=0.04). Consequently, we conducted a Pearson correlation analysis only with the group of bilingual infants to determine whether the variable discrimination scores and the variable of accuracy were correlated. As shown in Figure 36, a significant correlation between the two factors emerged, revealing

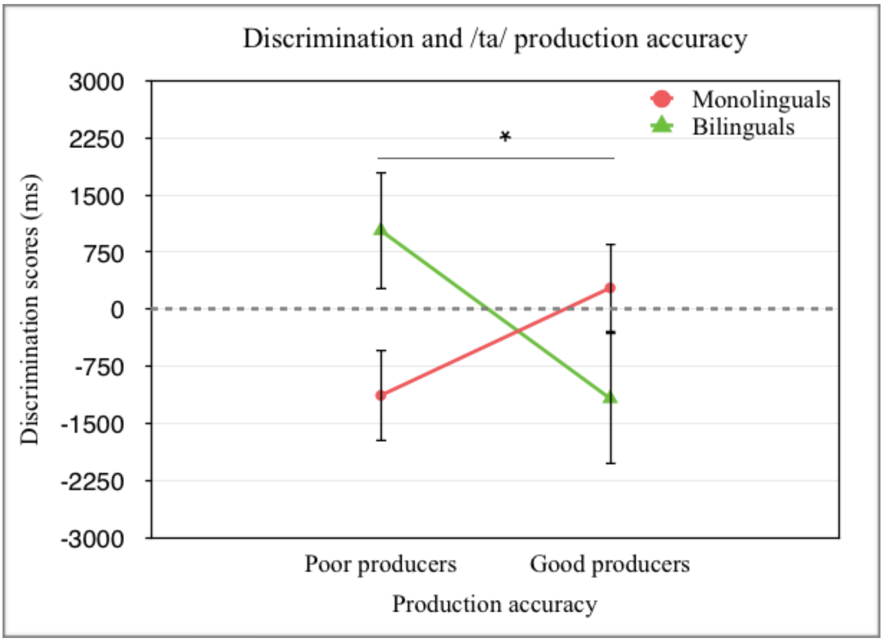

Figure 35. Mean of discrimination scores (difference in looking proportions between Same and Switch test trials) for monolingual and bilingual groups according to their production accuracy (poor producers scored below 3, good producers scored 3). Error bars represent standard errors.

that the more accurate bilingual infants' productions were, the more markedly infants preferred to listen to nonnative sounds than to native sounds ($r(20)=-0.439$, p=.04). Assuming that the results of better accuracy could also be a product of age, we conducted a follow up regression analysis including both the factor age (as a continuous variable accounting for days since birth) and accuracy performance (1-3) as predictors of discrimination.

The results showed no correlation of age combined with accuracy over bilingual infants' discrimination responses.

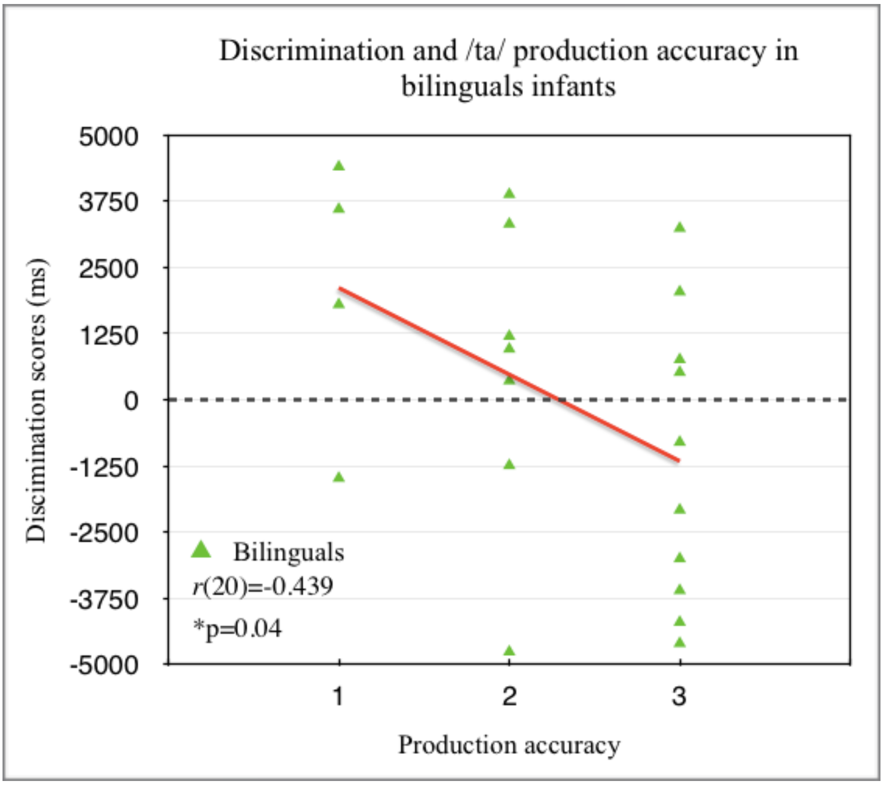

Figure 36. Relation between production accuracy groups (maximum accuracy scores were 3) and discrimination scores (difference in looking proportions between Same and Switch test trials) in bilingual infants.

4.5. Discussion

From the previous set of analysis we can conclude that the type of linguistic exposure during infants' first year of life affects their production behavior. Moreover, the results of the bilingual sample, with correlations between their patterns of production of native consonants and discrimination of nonnative consonants, drive an interesting new framework to interpret the results obtained in the discrimination studies.

4.5.1. Common developmental ground between monolingual and bilingual infants

Summarizing, first we found a common relationship between discrimination and babbling, without differences between language groups, suggesting that infants who babble during the consonant discrimination task show longer looking proportions in the nonnative trials and infants who remain silent show longer looking proportions in the native trials. Overall, there were no differences between monolingual and bilingual infants regarding their mean number of utterances by age. According to these results, we should assume that the maturational constraints in babbling are accounting for the development of utterance frequency. These set of results are in line with the results obtained by Oller et al. (1997) in which the frequency and onset of canonical babbling was also equivalent between language groups.

4.5.2. Linguistic experience influences infants' production patterns

Despite the above mentioned similarities, we found differences between language groups. First, accounting for the production behavior of infants at 7, 12 and 15 months of age, we observed that the number of babbling infants during a consonant discrimination task was higher for bilinguals. The relative increase of bilingual babblers in comparison to monolingual babblers was significant at 7 and 15 months, precisely the ages when bilingual infants show a preference in discrimination for the nonnative sounds (as opposed to the preference of native sounds at 12 months).

Second, the effects of imitative babbling on discrimination were exclusively observed in bilingual infants. That is, only in the case of infants raised in bilingual environments do higher rates of imitative utterances correlate with a preference to listen to novel nonnative contrasts. Thus, our results in frequency in bilingual infants' productions concur with the results obtained in the studies by DePaolis et al. (2013), who posited that the more the infants practice a consonant the less that particular (native) consonant holds their attention.

Third, regarding the accuracy of the native /t/ sounds that infants produced in their imitative utterances, we also observed differences between monolingual and bilingual infants. Monolinguals' production accuracy remained stable whereas bilingual infants significantly improved the quality of their imitative /ta/ productions from 12 to 15 months. Crucially, the accuracy of /t/ consonant productions and the preference to listen to nonnative contrasts were correlated in the case of bilinguals. The less accurate producers preferred to listen to the native sounds in test and the more accurate producers preferred to listen to the nonnative sounds in test.

Additional analysis revealed other effects of language exposure. Our results show that only at 12 months the degree of bilingual exposure influences infants' number of productions. At this specific age, a more monolingual environment correlates with a higher rate of imitative productions. Such effect disappears at 15 months, which could be interpreted as a delay of bilinguals to reach the same milestone at imitative productions than monolinguals. However, the absence of an interaction between language and age on imitative productions does not allow to support the bilingual delay hypothesis.

Our findings are in line with the recent results by Bruderer et al. (2015) obtained with 6 month-old infants. Their study showed that the impairment of the tongue articulatory movement involved in the productions of dental sounds, also impaired infants' ability to react to a retroflex contrasts. The authors' interpreted such results as a evidence of the need of sensory-motor information for consonant discrimination. Our results provide additional information in line with their interpretation.

Furthermore, the shift between 12 months and 15 months in discrimination and production abilities of bilingual infants ressemble the results from previous studies by DePaolis et al (2011). The 12-month-old bilingual group shows a familiarity preference in the discrimination task and a lower number of productions in comparison to monolingual infants. At 15 months, we find a novelty pattern of discrimination of nonnative consonants and an increase in their number of utterances, which match the ones of monolingual infants. DePaolis et al. (2011), found that infants who can produce only one consonant prefer to attend to the acoustic presentation of that consonant more than to other consonants, whereas infants who can produce two or more consonants prefer to attend to novel sounds that are not present in their productive repertoire. Hence, although the measures of each study are very distinct, the results of both studies could suggest that at 12 months bilinguals' representation of consonants is less defined than at 15 months.

In sum, from our results we can conclude bilingual infants babble more than monolingual infants during a discrimination task. Furthermore, the number and the accuracy of their native consonant productions correlates with a nonnative consonant preference in discrimination. Nevertheless, from our results we can not confirm the direction of the correlations between perception and production. In the general discussion we address three possible interpretations, taking together our results of discrimination and production.

5. General discussion

Young infants are sensitive to many phonetic contrasts present in the languages of the world. However, throughout their first year of life their sensitivity to native distinctions is sharpened (Kuhl et al., 2006), while their ability to perceive nonnative distinctions declines (Werker & Tees, 1984). Perceptual narrowing is thus clearly shaped by linguistic experience (Bosch & Sebastian-Gallés, 2003; Anderson et al., 2003). However, perceptual narrowing is also influenced by biological factors. Data with preterm infants show that differences in language exposure do not always modify infants' brain responses to native and nonnative contrasts (Peña et al., 2012), unless such differences occur within the constraints of a critical period. Therefore, comparing bilingual infants to monolingual infants, equating for maturational age, sets an appropriate experimental condition to explore the effects of linguistic exposure on phonetic narrowing.

The current dissertation aimed at determining the influence of linguistic experience in the process of perceptual narrowing of consonants. This manuscript reports the discrimination and production abilities of both language groups, detailing the course of their respective processes of perceptual reorganization, from their initial stage of broad-based acoustic sensitivities to their final stage of native phonetic perception. Thus, we have obtained measures for discrimination and production from monolingual and bilingual populations within the course of 11 months in development, from 7 to 18 months of age.

Following a habituation paradigm (Narayan et al., 2010), in *Chapter 2* we tested monolinguals' and bilinguals' ability to discriminate a native versus a nonnative consonant contrast (/ta/ vs /Ta/). Our findings reveal that monolingual and bilingual infants start with equivalent sensitivities for nonnative consonant contrasts. At 7 months, both groups detect the difference between the native unvoiced dental plosive /t/ and the nonnative retroflex contrast /T/. At 12 months, and in line with previous studies testing monolinguals with the same phonetic contrasts (Werker et al. 1984, Anderson et al. 2003), 12 month-old monolinguals did not react to the difference between native and nonnative distinctions. Nevertheless, unlike 7 month-olds, 12 month-old bilingual infants listened longer to their native than to the nonnative contrast, suggesting a variant pattern of development. At 15 months the difference between both groups remained. As expected, monolinguals did not discriminate, while bilinguals detected the difference between categories. However bilinguals also showed a switch in the direction of their preference when compared to the bilingual 12-month-old group, with longer looking times in the nonnative condition. Only at 18 months did bilinguals cease to discriminate between conditions. In sum, we can conclude that despite both language groups sharing a common pattern of discrimination at 7 months, in the bilingual case the sensitivity period for nonnative consonants expands by 6 months.

5.1. Critical period or attention?

Our results could be interpreted in two possible ways. First, the enhanced period of consonant sensitivity in bilinguals could be interpreted as a delay of the closure of perceptual narrowing. In such case, we should take into consideration the hypothesis that bilingualism modifies the critical period of sensitivity to nonnative consonants (Werker & Hensch, 2012). However, a second possible interpretation could also explain our results. Previous literature also shows that bilingual infants present heightened acoustic (Petitto et al., 2012; Liu & Kager, 2013) and heightened attentional resources for language (Sebastián-Gallés et al., 2012). Therefore, we should also consider the possibility that bilingual infants narrow their phonetic repertoire at the same time than monolingual infants, but that the differences in their attentional systems drive the differences in our behavioral task. On behalf of this argument, we also concluded that the attrition rates were higher in the monolingual than in the bilingual population, regardless of the age. Also the dynamics of the development within bilinguals' discrimination pattern, with a novelty-familiarity-novelty switch, could suggest that attention or preference play are more than just an automatic detection of a change. As mentioned in the corresponding discussion, further experiments implementing a different task that equalizes the attentional factor in both language groups would shed more light onto which underlying mechanism can account for our results.

5.2. Both the kind and amount of exposure matter

In *Chapter 3* we analyzed the effects of the linguistic input on the process of perceptual reorganization. We have reported effects of the degree of bilingualism and the degree of language exposure on infants' discrimination responses. We concluded that the most crucial effect of degree of bilingualism occurs at 15 months. At that age, the degree of exposure to one or two languages predicts the size of infants' discrimination. Moreover, the influence of the degree of bilingualism cannot be explained by language specific effects. Hence, the different degrees of discrimination predicted by monolingual and bilingual dominant environments at this age are showing rather a cumulative impact of the unique bilingual experience more than an effect of the bilingual input at such age. Considering the absence of effects of the degree of bilingualism at 7 months and the strong trend at 12 months, we can conclude that the role of the amount of exposure to two languages gradually increases, becoming a more reliable predictor of the amount of discrimination, until it becomes determinant at 15 months.

Continuing with the effects of the linguistic input, we also found that, at 7 and 12 months, the specific properties of language influence infants 'discrimination responses. Predominantly Catalan environments follow the classic pattern of consonant sensitivity of monolinguals, with a decay in sensitivity from 7 to 12 months. Conversely, Spanish dominant environments show reduced sensitivity at 7 months and enhanced sensitivity at 12 months. We posited that both the size of the phonetic repertoire and phonetic density could be explaining the differences in discrimination driven by type of language input. Again, further experiments should be conducted to determine the causal factor. Regarding the size of phonetic repertoire hypothesis, cross-language studies contrasting the discrimination in languages with small and large phonetic repertoires might answer the question. The phoneme density hypothesis could be explored by testing native contrasts which share the same phonetic space in Catalan and Spanish.

In line with the discrimination results, in *Chapter 4* we also observed an effect of language exposure on babbling. Bilingualism increases infants' rates of utterances and furthermore, the higher number of imitative utterances was, the higher the accuracy of infants' productions correlated with the discrimination of nonnative contrasts. Crucially, our findings could not have even been observed in monolingual populations, because by the time monolingual infants start producing canonical babbling, at 7 months, they are already losing sensitivity to nonnative sounds. Hence, the information obtained from bilingual infants opens a new window for understanding the interplay between discrimination and production abilities in infancy.

5.3. Listening to speak or speaking to listen?

We could interpret our results of production in three possible ways. According to the classic theories of perception, our results in production could be an effect of infants' discrimination performance. That is, better perceivers produce better. Also, producing more tokens of the items during the experiment increases infants' exposure to their native (experimental and own) sounds. However, this hypothesis cannot explain why better perceivers also have higher babbling rates.

Therefore, we should also take into consideration the possibility that production influences discrimination as well as discrimination influences production. From this perspective, the correlation of better perception of nonnative contrasts with the increase in the rate of /ta/ productions would imply that producing more sounds heightens the discrimination of nonnative sounds, as suggested by Bruderer et al. (2015). Consequently, the increased number of relevant productions, together with better discrimination abilities, may also lead infants to accurately perform when they reproduce their native sounds. Derived from this approach we should consider the possibility that bilingual infants increase their production rates as a compensatory mechanism to increase their perception of sounds, and hence, they produce more imitative utterances in order to enhance their success at attending only to the relevant native category during the period of increased discriminability of non relevant sounds.

A third approach would question the previous two arguments, as follows. It could also be the case that the effects we found are task - dependent. If, as suggested by the differences in attrition rates between language groups, bilingual infants show increased interest in our experimental task, and, consequently, they are more engaged with the stimuli than monolingual infants, we may also expect that they show increased discrimination, produce more utterances, and increase their production accuracy as a result of motivation.

5.4. What production can say about discrimination

Importantly, our results with production help to assess the discrimination hypothesis. If the nonnative discrimination in bilinguals implies that perceptual narrowing is not achieved util 18 months, how can bilingual infants produce a native category accurately when they haven't yet acquired it? The mismatch between the discrimination responses at 15 months and the simultaneous accuracy in infants' productions suggests that perhaps bilinguals acquire their native category earlier than what the standard interpretation of the results we proposed would suggest.

That is, bilinguals'sensitivity to nonnative contrasts may be an independent process than phoneme category fixation. Indeed, if production facilitates perception of nonnative contrasts, bilinguals could use production as a strategy to succeed at better perceiving non-prototypical sounds. Therefore, the results obtained in our discrimination studies could be showing responses to heightened acoustic sensitivity *after* perceptual narrowing, rather than an expanded period for the process of perceptual reorganization. As we already mentioned, further studies using a different techniques may clarify the conflicting theories.

5.5. Implications of our results for language acquisition

In the introduction we have exposed the relevance of phoneme perception for later language acquisition. Previous studies correlate late sensitivity to nonnative contrasts with lower vocabulary comprehension (Conboy et al., 2005) and also with slower language growth and lower complexity in sentence productions (Kuhl et al., 2005). Studies with electrophysiological data and meta-analysis performed on vowel acquisition studies (Cheour et al., 1998; Rivera-Gaxiola et al., 2005; Tsuji & Cristia, 2015) describe an inverse correlation between infants' timing of acquisition of native sound categories and the decay in discrimination of nonnative contrasts. In the introduction we have extendedly reported that the maintenance of initial sensitivities happens simultaneously in monolingual and bilingual infants.. However, bilinguals show sensitivity to nonnative contrasts for a longer period than monolinguals, at stages in which their first words are already being acquired (Bergelson and Swingley, 2013). Hence, we should expect that bilingual infants present a delay in language acquisition.

Nonetheless, this implication is far from what we observe at later stages in bilingual infants. Bilingual infants acquire their first words at around the same ages as monolinguals (Pearson et al., 1993; Oller et al., 1997; Petitto et al., 2001) and their total vocabulary sizes, when accounting for the words in both of their languages, are comparable (Pearson et al., 1993; Hoff et al., 2012; Petitto et al., 2001), regardless the additional challenges of learning language in bilingual environments. Therefore, the increased sensitivity to nonnative sounds in bilinguals must not be considered as a cost for language development, as previous studies with monolingual populations suggest. Rather, if bilingual infants have already narrowed their repertoire and they still show sensitivity to nonnative distinctions, such sensitivity could potentially facilitate their perceptual attunement to finer-grained distinctions present in their linguistic input. If, alternatively, infants are showing signs of an expanded learning period of phoneme acquisition, they could be compensating for the ambiguities in the input by means of the interaction of their perceptual systems with their distinct cognitive

(Kovács et al., 2009), attentional (Weikum et al. 2007, Sebastián-Gallés et al., 2012) or even speech production abilities.

Testing how bilinguals' enhanced discrimination interacts with higher order linguistic tasks - such as object mapping, speech segmentation or categorization - may shed new light onto language acquisition and bilingualism. On the one hand, it might aid at differentiating some confounded factors observed in the literature of monolingual infants - which can potentially lead one to misinterpret correlations for causation effects - and, on the other hand, it might also open a new set of possibilities to study the scientifically underrepresented - and yet world-wide increasing - bilingual population.

6. CONCLUSIONS

Our results show that linguistic experience shapes the process of phonetic acquisition. Bilingual infants are able to discriminate foreign distinctions they have not been exposed to for six months longer than monolingual infants. Moreover, a the degree of bilingualism correlates with discrimination at 15 months, which suggests that the amount of bilingual exposure has an impact on perceptual reorganization of sounds. The characteristics of each of their two native languages also influences nonnative discrimination responses at earlier stages in development, which demonstrates that the type of language exposure is also relevant. The analysis of infants' pattern of productions provided a new tool to investigate the underlying mechanisms involved in phonetic acquisition. Our auditory discrimination task primed infants' production behavior differently as a function of their linguistic background. Bilingual infants produce more sounds than their monolingual peers, and better accuracy and higher rates of imitative babbling correlates with better discrimination of nonnative sounds.

Hence, the detailed analyses of bilinguals' behavior in a very simple and very known tasks provides researchers with an extremely rich tool of investigation. Tasks such as the infant habituation procedure, which has been highly used in the literature, contains much more information to understanding the specificities and similarities among infants with different linguistic background than previously realized. Our work is a first preliminary step in this direction.

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Appendix

The following tables present describe the acoustic characteristics of the acoustic stimuli used in the visual habituation paradigm.

Dental Stimuli	Token	Duration (ms)	Avg Pitch	Pitch min	Pitch max	Pitch range
[ta]	1	53,39	145,23	101,68	198,66	96,98
[ta]	2	51,05	210,84	109,76	313,18	203,42
[ta]	3	48,25	189,90	102,71	285,61	182,90
[ta]	4	51,12	192,50	108,29	264,77	156,48
[ta]	5	52,46	198,50	109,14	304,60	195,46
[ta]	6	46,22	170,00	102,63	238,10	135,47
[ta]	7	54,09	200,60	108,80	286,77	177,97
[ta]	8	45,30	169,90	102,73	238,09	135,36
	Average	50,24	184,68	105,72	266,22	160,51
	SD	3,29	21,41	3,55	38,96	36,22

Retroflex	Token	Duration (ms)	Avg Pitch	Pitch min	Pitch max	Pitch range
[Ta]	1	54,07	168,00	100,95	232,47	131,52
[Ta]	2	51,70	218,70	108,22	318,48	210,26
[Ta]	3	56,20	203,00	109,74	280,35	170,61
[Ta]	4	57,77	166,70	107,37	246,56	139,19
[Ta]	5	52,76	196,80	105,46	299,33	193,87
[Ta]	6	53,86	175,40	107,37	242,19	134,82
[Ta]	7	53,36	211,10	107,34	306,26	198,92
[Ta]	8	53,32	154,10	103,06	219,19	116,13
	Average	54,13	186,73	106,19	268,10	161,92
	SD	1,95	23,69	2,89	37,64	36,00

Dental Stimuli	Token	F1 (hz)	F2 (hz)	F3 (hz)	F4 (hz)	Intensity (dB)
[ta]	1	901,98	1534,42	2621,22	3919,68	80,45
[ta]	2	820,51	1630,79	2747,29	3547,79	80,27
[ta]	3	835,82	1588,30	2596,92	3955,95	80,31
[ta]	4	910,06	1555,65	2547,00	3810,37	79,96
[ta]	5	908,44	1594,42	2696,57	2991,30	78,73
[ta]	6	863,92	1461,55	2577,27	3334,95	79,78
[ta]	7	864,08	1506,51	2236,41	2586,90	79,32
[ta]	8	860,66	1457,32	2608,22	2666,11	78,78
	Averag	107,58	182,17	326,03	333,26	9,85
	SD	310,13	551,68	922,95	1309,12	28,23

Retroflex Stimuli	Token	F1 (hz)	F2 (hz)	F3 (hz)	F4 (hz)	Intensity (dB)
[Ta]	1	904,59	1544,53	2599,93	4002,71	79,40
[Ta]	2	916,75	1602,94	2636,06	3912,71	81,77
[Ta]	3	875,10	1310,93	1537,01	2564,26	79,65
[Ta]	4	897,64	1576,41	2649,73	4011,34	78,74
[Ta]	5	842,93	1642,27	2593,80	2675,71	76,70
[Ta]	6	886,15	1433,13	2057,05	2622,22	77,39
[Ta]	7	888,63	1550,36	2542,91	3929,21	78,05
[Ta]	8	854,92	1498,81	2454,69	2802,07	78,89
	Average	106,87	187,35	306,84	350,26	9,86
	SD	314,51	548,65	926,14	1370,74	27,91