Developmental changes in vowel perception: how input interplays with initial perceptual biases

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Abstract

The present dissertation aims at analyzing the interplay between initial acoustic biases and language exposure during acquisition of language in the first year of life. This is a critical period in development because it is when phonetic categories are attuned to the native language. This goal is addressed by integrating the results from two developmental studies. The first study explores the presence of asymmetries in vowel perception in infants from 4 to 12 months of age, as a function of the acoustic salience and distributional properties in the test language. The second study investigates the previous contrasting results on vowel perception in 8-month-old infants growing in bilingual environments, and in particular and their relationship with task demands and the properties of the bilingual input. The results emerging from these studies point to two developmental trends. On one hand, asymmetries in vowel perception are modulated by acoustic biases before and during perceptual reorganization, and by distributional cues after perceptual reorganization. On the other hand, discrimination abilities of 8-month-old bilinguals parallel those of monolinguals when tested with an Anticipatory Eye Movement procedure, highlighting the importance of task demands in determining infants' performance.

Resum

L'objectiu d'aquesta tesis és analitzar la dinàmica que s'estableix entre els biaixos acústics i l'experiència amb el llenguatge durant el primer any de vida. Aquest és un període decisiu durant el qual les categories fonètiques s'ajusten a les propietats de la llengua materna. Aquest objectiu s'assoleix integrant els resultats de dos estudis. En el primer

estudi s'explora la presència d'asimetries en la percepció de les vocals en bebès de 4 a 12 mesos d'edat, en funció de la saliència acústica i les propietats distribucionals de la llengua. El segon estudi investiga els resultats contradictoris obtinguts amb bebès de 8 mesos d'edat bilingües, i la seva relació amb les demandes de la tasca i les propietats de l'input bilingüe. Els resultats d'aquests estudis indiquen dos tendències al desenvolupament. Per una banda, que les asimetries en la percepció de les vocals són modulades per biaixos acústics abans i durant la reorganització perceptiva i per les propietats distribucionals després de la reorganització perceptiva; per l'altra banda, els resultats mostren que les habilitats de discriminació dels bilingües de 8 mesos d'edat són corresponents a les dels monolingües quan es fa servir un procediment d'anticipació de la mirada, posant en rellevància la importància de les demandes de la tasca en determinar el rendiment dels bebès.

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1. INTRODUCTION

1.1. Biased to language: Initial abilities

The attunement of our perceptual mechanisms to language begins even before we are born. This is supported by newborns' ability to recognize their mother's voice (DeCasper & Fifer, 1980) and their maternal language (Mehler et al., 1988) just a few hours after birth. In fact, infants begin the task of language learning with several initial biases that help triggering the attunement (Sebastián-Gallés, 2007; Werker & Curtin, 2005). From the outset, neonates treat the speech signal as special. They orient towards speech sounds (Brody, 1984) and, more interestingly, they prefer to hear to speech rather than to other comparably complex non-speech sounds (Vouloumanos & Werker, 2004; Vouloumanos & Werker, 2007). Additionally, newborns are sensitive to prosodic boundaries in spoken language (Christophe, Dupoux, Bertoncini, & Mehler, 1994; Christophe, Sebastián-Gallés, & Mehler, 2001); are able to discriminate between languages belonging to different rhythmic categories (Nazzi, Bertoncini, & Mehler, 1998); they can distinguish between multisyllabic words with different stress patterns (Sansavini, Bertoncini, & Giovanelli, 1997) and between disyllables differing in the location of stress (Spring & Dale, 1977); discriminate syllable-like stimuli from non-syllable like stimuli (Bertoncini, 1981); or discriminate between content and function words (Shi & Werker, 2001), to name just some of newborns' innate language abilities. Moreover, neuroimaging studies add converging evidence to the special status of speech in early development, given the structural and functional similarities between the organization of infants' speech processing and that of adults (Dehaene-Lambertz, Hertz-Pannier, & Dubois, 2006).

Regarding phonetic perception, infants are initially able to discriminate between many pairs of phonemes, regardless of whether these contrasts are present or not in their surrounding language. A seminal study by Eimas et al. (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) revealed infants' initial phonetic abilities, showing that 1- to 4-month-old English-learning babies discriminated categorically along the Voice Onset Time (VOT) bilabial stop [pa]-[ba] continuum. Infants' discrimination of the same physical difference was more precise when the stimuli crossed the adult phonetic category boundary than for two stimuli within the same category (Eimas et al., 1971). Along similar lines, other studies revealed that infants can discriminate the /r/ and /l/ categories along the /r-l/continuum (Eimas, 1975), syllable-final stop consonants (Jusczyk, 1977) or place of articulation differences (Eimas, 1974).

In later studies, these initial discrimination abilities were shown to extend to the perception of non-native phonetic contrasts. The perception of the VOT bilabial stop [pa]-[ba] continuum was studied in infants from Kiyuku families, a Bantu language in which the English voiced/voiceless distinction is not used. Results indicated that Kiyuku infants discriminated categorically the [pa]-[ba] continuum, proving that the prior exposure to the [pa]-[ba] contrast was not necessary to succeed in phonetic discrimination (Streeter, 1976). Since then, many studies have uncovered infants' initial discrimination of other non-native consonant contrasts. For example, English-learning 5 to 17-

week-olds can discriminate the Czech voiced alveolar fricative [za]-[r̝a] contrast, differing in stridency (Trehub, 1976). It has also been observed that 6-8-month-old infants were able to discriminate the Salish velar-uvular ejective [k'i]-[q'i] contrast and two Hindi consonant contrasts, the dental/retroflex stop [t̪a]-[ʈa], and the voiceless aspirated/breathy voiced dental stop [t^{h}a]-[d^{h}a] (Anderson, Morgan, & White, 2003; Werker, Gilbert, Humphrey, & Tees, 1981; Werker & Tees, 1984).

Discrimination of native and non-native contrasts has been found with numerous phonetic distinctions. However infants do not always succeed in all the contrasts tested, suggesting the need of extended exposure to the input for some contrasts to be discriminated. For instance, English-learning infants have difficulties in discriminating native contrasts involving the fricative sounds/f/, /θ/ and /ʃ/ (Eilers, Wilson, & Moore, 1977). In addition, a recent study shows that the Filipino nasal alveo-dental/velar [na]-[ŋa] cannot be discriminated by English-learning nor Filipino-learning infants at 4-5 months of age (Narayan, Werker, & Beddor, in press). The authors of these studies argue that the infants' failure to discriminate these sounds is related to the low acoustic salience of the contrasts tested. Thus, infants' initial abilities do not allow them to discriminate all the phonetic contrasts in the world's languages. Rather, very early discrimination abilities in infants seem to be constrained by the acoustic properties of the phonemes tested.

Similarly to what happens with consonant contrasts, the literature contains several reports about early discrimination of both native and non-native vowel contrasts. Accordingly, English 2- to 4-month-olds were able to distinguish the /a/-/i/, /i/-/u/ and /ɪ/-/i/ pairs of native contrasts (e.g. Polka & Werker, 1994; Swoboda, Kass, Morse, & Leavitt, 1978; Trehub, 1973) and 6-month-old German infants discriminated the German /ɪ/-/e/,/e/-/i/, /ɪ/-/ɛ/, /o/-/ʊ/ distinctions. Regarding non-native vowel contrasts, it has been found that Canadian-English 5- to 17-week-olds discriminated the French oral/nasal [pa]-[pã] (Trehub, 1976) and that 6-8-month olds could discriminate the German /u/-/y/ and /ʊ/-/Y/ contrasts (Polka & Bohn, 1996). Interestingly, Polka and Bohn (2003) realized that several of the studies exploring infants' vowel perception reported asymmetries in the infants' discrimination behavior for vowel contrasts (both native and non-native), such that the vowel occupying the most peripheral position within the vocalic space was more easily discriminated than the other. These asymmetries can be explained by the Natural Referent Vowel hypothesis (Bohn, 2007), which proposes that peripheral vowels have a privileged perceptual status, such that they act as perceptual anchors when compared to other vowels. The authors proposed that this advantage of peripheral vowels reflects an innate bias present in infants which is independent of the language being spoken in their environment.

These early phonetic abilities in infants contrast with adults' speech perception abilities, which is highly attuned to the relevant contrasts of the native language (Dupoux, Pallier, Sebastián-Gallés, & Mehler, 1997; Otake, Hatano, Cutler, & Mehler, 1993; Otake & Cutler, 1996) but relatively imprecise in discriminating foreign contrasts. The adults' difficulties with non-native phonetic contrasts are well known (e.g.

Flege, Munro, & MacKay, 1995; Goto, 1971; Oyama, 1976), and the literature has shown that even simultaneous bilinguals[1] can experience some difficulties in discriminating phonemes of their non-dominant native language (Sebastián-Gallés, Echeverría, & Bosch, 2005). The stark contrast between the wide sensitivity of infants and the narrow attunement in adults might mean that, the infant speech perception system shifts from a language-universal mode (whereby all infants show the same abilities and biases regardless of the linguistic environment), to a language-specific adult-like pattern. But, when and how does the native language/s begin to influence infants' phonetic perception?

1.2. Perceptual reorganization in phonetic perception

The timing when infants get attuned to the phonetic properties of their native language is a topic that researchers have been investigating over the last 40 years. It has been found that indeed, during the first year of life, infants' speech perception abilities move from an initial general stage to a language-specific perception, showing an improvement in the perception of native contrasts paired with a decline in the perception of non-native sounds. However, research has also offered evidence that some phonetic contrasts deviate from this developmental pattern.

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[1] Simultaneous bilinguals have acquired both languages from birth and are highly proficient. However, a dominant language prevails.

1.2.1. Decline in non-native perception

The influence of experience with language on non-native phonetic perception was first observed in the domain of consonant contrasts. The foundational study of Werker and Tees (1984) provided strong evidence of a shift from an unconstrained, language-general perception towards a more specialized, native-like perception of speech sounds. This shift takes place around 10-12 months of age, at least for some consonantal contrasts. In this work, Werker and Tees (1984) compared 6-8-, 8-10- and 10-12-month-old English infants and 11-12 month-old Hindi and Thompson (a Salish language spoken by Native Americans in British Columbia) infants on their perception of the Salish velar/uvular ejective [k'i]-[q'i] contrast and the Hindi dental/retroflex stop [ʈa]-[t̪a] contrast. The results showed that most of the infants aged 6-8 months could discriminate both non-English contrasts; by 8-10 months a smaller percentage could discriminate the non-native contrasts, and by 10-12 months the infants were already performing as poorly as English speaking adults. However, infants being raised to speak Hindi or Thompson could still discriminate their respectively relevant contrasts at 11-12 months of age.

These findings show that the decline in the ability to discriminate non-native phonetic contrasts occurs within the first year of life. Supporting Werker and Tees (1984) results, data on additional consonant contrasts have been obtained, most of which showing a decline in performance with age. For instance, 4½ month-old but not 12-month-old Spanish-learning infants were able to discriminate the fricative Catalan /s-z/ contrast (Bosch & Sebastián-Gallés, 2003b). Along a similar line, 6-8-month-old Japanese-learning infants discriminated successfully the English /r-l/, but they could not discriminate this contrast, irrelevant in Japanese phonology, by 12 months of age (Tsushima et al., 1994). Finally English-learning infants showed a decline in their performance on the isiZulu /ɬ/-/ɮ/, /ɓ/-/b/ and /k^h/-/k'/ contrasts from 6-8 to 10-12 months of age (Best & McRoberts, 2003). These changes in infants' sensitivities are the consequence of what has been called *perceptual reorganization* processes that result from linguistic experience (Werker & Lalonde, 1988).

Nevertheless, there are some exceptions to the trend described above, whereby infant's discrimination of contrasts or properties that are uninformative in their native's language declines. For example, American infants retained the ability to discriminate the apical vs. lateral isiZulu click consonants /|/-/||/ at all ages tested between 6 and 14 months old (6-8, 8-10, 10-12 and 12-14 months of age, Best, McRoberts, & Sithole, 1988). Moreover, English speaking adults tested in the same study were also able to pick out the differences between the isiZulu consonants. The explanation for these persisting discrimination abilities (i.e. the lack of decline) derives from the fact that the consonants tested deviate too greatly from the phonetic space that defines the English phonological repertoire. Hence, Best and coworkers proposed that listeners failed to assimilate those sounds as potential phonological elements, perceiving them as non-speech sounds and therefore being able to distinguish them on the basis of acoustic properties (Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995). Another exception to the decline in sensitivity to non-native contrasts is found in the study by Polka, Colantonio, & Sundara (2001), which looked at the discrimination of the English alveolar stop/dental fricative /d/-/ð/ contrast by French- as well as by English-learning infants at 6-8 and 10-12 months of age and English speaking adults. This contrast is phonemic in English but not in French. As expected, performance was poorer for French participants compared to English adults, whereas no group differences were seen in 6-8-month-olds. Yet surprisingly, the experiment failed to show an effect of language experience in the 10-12-month-old English-learning infants, as it would have been expected from their accumulated experience with this contrast. Moreover, all infants (6-8- and 10-12 month-olds in both French and English groups) displayed a fairly poor discrimination ability altogether comparable to that of French-speaking adults. These results suggest that for native listeners, developmental improvement in perception of the /d/-/ð/ consonant contrast takes place with increasing language experience after 12 months of age.

Concerning the developmental changes involving the perception of vowels, language-specific effects seem to be present even earlier than for consonants, at around six months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994). Kuhl and collaborators (1992) investigated the perception of non-native and native vowels in English and Swedish infants, examining the internal structure of vowel categories in comparison to the internal structure of non-native vowel categories. In particular, Kuhl et at. (1992) addressed the perception of the English vowel /i/ (which is a prototype in American English but a non-prototype in Swedish) and the Swedish vowel /y/ (prototypical in Swedish but not in American English). American and Swedish 6-month-old infants were familiarized in a conditioned head-turn procedure to one of the two vowels and were then tested with two types of trials: change trials, where the infants heard the non-familiarized vowel, and control trials, in which the test vowel was the same as the one in the familiarization. When infants were familiarized to the prototypical vowel of their own language, they failed to discriminate non-prototypical members of that category. However, if the familiarization was to the prototype of the non-native vowel, infants' performance discriminating that vowel from a close variant was enhanced. This pattern of results was described as the *Perceptual Magnet Effect*. The driving idea is that language experience warps the underlying acoustic space, creating a filter through which language is perceived (Kuhl et al., 1992; Kuhl et al., 2008). This language-specific sieve gives way to enhanced generalization around prototypical exemplars, while discrimination is retained for stimuli around the non-prototypical tokens. It is called *magnet* because the central member of the category seems to perceptually attract the exemplars that lay close in the phonetic space, rendering them less distinguishable. Therefore, according to Kuhl et. Al (1992), by 6 months of age, there is evidence of language-specific differences in the internal representation of vowel categories. Additionally, Polka and Weker (1994) studied the developmental pattern of discrimination of pairs of foreign vowel contrasts in a /dVt/ context using natural productions. They tested English infants at 4, 6-8 and 10-12 months and adults. Three vowel contrasts were examined, two foreign (German /u/-/y/ and /ʊ/-/Y/) and one native (/a/-/i/). The results revealed a decline in the ability to discriminate non-native contrasts during the first year of life: 4-month-old infants showed discrimination for all contrasts; 6- to 8-month-olds performance was already modified and 10-12-month-olds did not discriminate the German contrasts. This finding suggests that infants begin to attune to native vowel categories by six months of age, and that this attunement continues to evolve between 6-8 months and 10-12 months.

In a later study, Polka and Bohn (1996) failed to replicate the language-specific effects for the German /u/-/y/ and the English /ɛ/-/æ/ vowels contrasts in German and English 6-8- and 10-12-month-old infants. Each of these non-native contrasts consists of a vowel which is phonetically similar to one in the native repertoire and another which is completely unfamiliar: the German contrast /u/-/y/ is not phonemic in English, but English has a /u/ vowel similar to the German /u/, whereas the German /y/ is not a functional vowel category in English (cannot be assimilated to an English vowel). The same situation applies to the English /ɛ/-/æ/ contrast with respect to the German phonological repertoire: it is not phonemic in German, but German has a vowel similar to English /ɛ/ and /æ/ is not a functional category in German. Polka and Bohn's results showed no evidence of a decline so that both groups of infants (English- and German-learning) discriminated successfully native and non-native contrasts at 6-8 and at 10-12 months of age, although the performance in the /ɛ/-/æ/ contrast was fairly poor overall. As Bosch and Sebastián-Gallés (2003a) noted, these controversial results bring into discussion the different kinds of factors that can play a role in facilitating or hindering the perception of differences between the stimuli (such as number of contrastive vowels in the system, distribution in the vowel space, frequency of occurrence in the language or prototypicality of the exemplars).

Besides the behavioral findings discussed above, electrophysiological studies have produced further evidence for a shift from general to language-specific abilities. The pioneering work of Cheour et al. (1998) addressed the neural correlates of native and non-native vowel perception recording event-related potentials (ERPs) from a sample of Finnish (studied longitudinally at 6 and at 12 months) and Estonian infants (evaluated only at 12 months of age). They investigated language-specific memory traces analyzing the mismatch negativity (MMN) difference potential, an electrophysiological brain response automatically elicited by infrequent events (deviant stimulus) occurring in the context of an homogenous repetitive series of events (standard stimuli). The MMN response increases with larger acoustic distances between the standard and the deviant stimuli. Cheour et. al (1998) used two vowels that belong to Finnish and Estonian (/e/ and /ö/) and one vowel that is phonemic only in Estonian (/õ/). They used /e/ as a standard, being /ö/ and /õ/ the deviant stimuli, with a probability of occurrence of 0.1 for each. That is, infants listened to a series containing the standard stimuli /e/ 80% of the time, with occasional occurrences of deviants (20%). Thus, given that the acoustic distance is bigger between /e/ and /õ/ than between /e/ and /ö/, a larger MMN to the first pair of vowels expected. Indeed, that was what happened with 6-month-old Finnish infants. But in contrast, at 12 months of age the same Finnish infants had a much smaller MMN amplitude for the Estonian /õ/ than for the Finnish /ö/, showing that the MMN amplitude was modulated by the native phonological structure (i.e. increases for native phonemes and decreases for non-native ones). Accordingly, 12-month-old Estonian infants, for whom all the vowels belonged to their native repertoire, showed a larger MMN for the /õ/ than for the /ö/, reflecting the greater acoustic differences from /e/ to /õ/ than from /e/ to /ö/.

Rivera-Gaxiola, Silva-Pereyra, and Kuhl (2005) also used electrophysiological measures (ERPs) to explore the developmental pattern of native and non-native phonetic contrasts, but focusing on consonants. They reported a longitudinal study of English-learning infants at 7 and at 11 months of age where they measured the MMN difference waves to Spanish and English consonants differing in VOT. The standard stimulus was a voiceless unaspirated alveolar sound, common to both languages and perceived in Spanish as a /t/ and in English as a /d/. The deviant stimuli were two language-specific sounds: a voiced /d/ that is phonemic only in Spanish and a voiceless aspirated /t/ that is phonemic in English, but not in Spanish. The results revealed that the MMN amplitude increased significantly between 7 and 11 months of age to a native consonant change while decreased in response to a non-native contrast. Nevertheless, when individual infants' ERP components were examined, infants at 11 months still showed a differential response to the non-native contrast. This finding therefore suggests that many infants retain the capacity to discriminate non-native contrasts, at least at a neural level.

1.2.2. Improvement in the perception of native contrasts

Although many studies document a decline in non-native phonetic perception between 6 and 12 months, less research has been devoted to how native contrasts are processed during this age range. Kuhl, Stevens, Hayashi, Deguchi, Kiritani and Iverson (2006a) offered evidence supporting the notion of improvement in native perception between 6 and 12 months of age. The perception of the /r/-/l/ contrast was explored in American English-learning infants, for whom the contrast was native, and in Japanese-learning infants, for whom the contrast was non-native. The data demonstrated that the discrimination performance was equivalent in both groups of infants at 6-8 months but, at 10-12 months of age, American infants' performance improved while that of Japanese infants declined (albeit not completely). This pattern of results is consistent with perceptual learning and native-language facilitation before infants reach their first year of age. Nevertheless, as Sebastián-Gallés (2006) noted, it might be argued that this improvement in native discrimination abilities is compatible with the general development at 10-12 months: important changes in the maturation of the central auditory system and in the orientation/attentional network take place in this period.

Converging evidence indicating improvement in native perception by the first year of life comes from the work of Tsao, Liu and Kuhl (2006). Tsao et al. explored the time course in the development of native and non-native phoneme perception in a cross-language study with American and Taiwanese 6-8- and 10-12-month-olds. Discrimination of a Mandarin Chinese voiceless alveolo-palatal affricate/fricative contrast (/tɕʰi/-/ɕi/), which has been proved to be difficult to distinguish for English adults, was assessed with the head turn procedure. The results replicated the pattern found by Kuhl and collaborators (2006). American and Taiwanese infants' performance was equivalent at 6-8 months of age but it diverged at 10-12 months: Taiwanese infants showed a significant increase in native perception over time while American infants showed a decline, though they retained some discrimination ability. Moreover, a new group of American infants who were tested using an English (native) palato-alveolar affricate-fricative contrast (/tʃi/-/ʃi/), exhibited a significant increase in performance between 6 and 12 months of age.

However, not all the native phonetic contrasts follow this improvement pattern during the first year of life. In the study discussed above, Polka, Colantonio and Sundara (2001) explored the discrimination of the contrast /d/-/ð/ by French- and English-learning infants at 6-8 and 10-12 months of age and by adults. Besides failing to show a decline in non-native consonant perception in 10-12-month-old French infants, they observed that English infants did not improve their discrimination performance at 10-12 months of age, whereas adults performed at ceiling-level. In the same study they also analyzed the perception of the /v/-/b/ contrast as a control condition, which is native for both English and French infants. The same pattern of results was observed, with 6-8 and 10-12-month-old infants of both language groups performing alike but still worse than French and English adults. The authors proposed that additional exposure to the language beyond 12 months of age may be required to show a developmental change in these consonant contrasts. This need of extended experience with the language to discriminate a contrast has also been found in other studies. English-learning 4-years-old show a far better discrimination of the /d/-/ð/ contrast compared to English 10-12-month-olds and to French-learning 4-years-old, for whom the discrimination performance did not change throughout development (Sundara, Polka, & Genesee, 2006). Narayan et. al (in press) showed that Filipino-learning infants failed to discriminate the native alveo-dental/velar place of articulation /na/-/ŋa/ at 6-8 months of age, and that discrimination was not present until infants were 10-12-month-olds. In addition, Best and McRoberts (2003) tested the native-language fricative /s-z/ contrast in 6-8 and 10-12-month-old English-learning infants. Discrimination actually worsened with age (i.e., discrimination was more accurate in 6-8-month-olds than in 10-12-month-olds), thereby suggesting a decline in the discrimination of a native contrast. Nonetheless, the authors mentioned previous reports showing that older and younger infants have difficulties discriminating voicing distinctions in fricative sounds, even native ones (Eilers et al., 1977).

1.2.3. The bilingual perceptual reorganization process

The literature reviewed above sheds light on the developmental course of the perceptual reorganization process in monolinguals but, do their bilingual peers follow the same developmental pattern? Does bilingual exposure impact the perception of native-sound contrasts in a singular bilingual-specific way? Bosch and Sebastián-Gallés (2003a) explored infants' behavior at 4 and 8 months of age from three different linguistic environments: Catalan monolingual, Spanish monolingual and Catalan-Spanish bilingual families. Discrimination was assessed with a vowel contrast that is phonemic in Catalan but not in Spanish (/ɛ/ vs. /e/), using a familiarization-preference procedure. The results of 4-month-old infants replicated the language-general perception described earlier, and infants from all language groups were equally able to distinguish the contrast. For monolingual infants, Bosch and

Sebastián-Gallés observed a sensitivity decline in non-native perception, since at 8-months Catalan monolinguals maintained the ability to discriminate between the two vowels whereas Spanish monolinguals no longer showed a discrimination behavior. In addition, an improvement for native contrasts in Catalan monolinguals was seen (they showed greater differences to the vowels at 8 months than at 6 months). More interestingly, a bilingual-specific developmental pattern arose in the Bosch and Sebastián-Gallés (2003a) study. At 8 months of age bilingual infants performed like Spanish monolinguals, thus failing at the /e/-/ɛ/ discrimination. An additional group of 12-month-old Spanish-Catalan bilinguals was studied in order to ascertain whether this decline in sensitivity to a native contrast remained over time or whether, on the contrary, it disappeared in infants of older age. The results indicated that 12-month-old bilinguals recovered the discrimination ability, yielding a U-shaped pattern of native phonetic perception. In subsequent studies, this same pattern has been found with other contrasts such as the Catalan /s/–/z/ (Bosch & Sebastián-Gallés, 2003b) and the common Catalan and Spanish vowel distinction /o/-/u/. However, it was not replicated with the also common /e/-/u/ contrast (Sebastián-Gallés & Bosch, 2009). The bilinguals' success in the /e/-/u/ contrast might be attributed to the higher acoustical distance between these vowels in the vocalic space, rendering them more discriminable than contrasts that lay closer. Altogether, these findings reveal that infants receiving bilingual exposure show language-specific discrimination abilities for some contrasts, for which discrimination is accomplished at later age than monolingual infants.

Other studies offer evidence of bilinguals following the same pattern of native perception as monolinguals. Burns, Yoshida, Hill and Werker (2007) tested 6-8-, 10-12- and 14-20-month-old English-French bilinguals and English monolinguals' discrimination of stop consonants differing in VOT using an habituation procedure. The bilabial voiced/unvoiced /b/-/p/ contrast has a different phonemic boundary in English and French, such that [ba] is perceived by both groups as [ba], [pa] is perceived as [pa] by French speakers and as [ba] by English speakers, and [p^{h}a] is perceived by both groups as [pa]. Infants were habituated to the stimuli categorized differently in English and French, [pa], and tested in their ability to discriminate a change to [ba] and to [p^{h}a] tokens. The results of the 10-12-month-olds indicated a language-specific pattern of discrimination in both English monolinguals, who only dishabituated to the [p^{h}a] token, and in bilinguals, who dishabituated to [p^{h}a] and to [ba] (although this latter dishabituation was statistically marginal). At 14-20 months of age bilinguals and monolinguals showed the same discrimination pattern[2], although the performance of English monolinguals seemed to worsen from 10-12 to 14-20 months, (the dishabituation to the /p^{h}a/ token at 14-20 months of age was only marginal). Similarly, a related study showed that French-English bilinguals did not reveal a bilingual-specific pattern of discrimination of the English /d/-/ð/ contrast (Sundara, Polka, & Molnar, 2008). Sundara et al.'s results indicated that 10-12-month-old French-English bilingual and English monolingual infants discriminated the /d/-/ð/ contrast successfully,

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[2] However, it has to be noted that in a previous study testing French-English bilinguals with the same [ba-pa-p^{h}a] consonant contrast, the authors found a U-shaped pattern of discrimination like the one mentioned above, found with Catalan-Spanish bilinguals (Burns, Werker, & McVie, 2003).

while French monolingual infants did not. The authors suggested that although /d/and/ð/ overlap in cross-linguistic distributions (what would predict difficulties in discrimination for bilinguals), the high frequency of these phonemes in both English and French makes the contrast discriminable. However, there is evidence that older infants show a bilingual-specific pattern of discrimination for the /d/-/ð/ contrasts. Sundara et al. (2006) found that 4-year-old French-English bilinguals performed worse than their monolingual peers of the same age. In contrast, bilingual and monolingual adults were tested and did not differ in their performance. Therefore, these findings suggest that language experience facilitates bilinguals' perception of the /d/-/ð/ contrast well beyond the first year of life.

1.3. What mechanisms drive the attunement process?

As it has been illustrated in the previous sections, as infants grow up they become gradually attuned to the regularities of the input present in their environment. But, what mechanisms allow infants to extract the relevant information in the speech signal? It has been proposed that phonetic learning is based in a bottom-up analysis of the speech sounds, which detects the phonetic characteristics of the language. Research on infant language development has demonstrated that infants keep track of the distributional information contained in the input they hear. For instance, infants prefer frequent phonotactic patterns, revealing infants' awareness of the relative frequency of occurrence of segments in their language (Jusczyk, Luce, & Charles Luce, 1994, Sebastián-Gallés & Bosch, 2002) and 8-month-olds can make use of transitional probabilities between syllables to parse the speech stream (Saffran, Aslin, & Newport, 1996). Regarding phonetic learning, it has been demonstrated that infants are sensitive to the distributional properties of the input to build up language-specific categories. Maye, Werker and Gerken (2002) studied the effects of exposure to different frequency distributions of speech tokens extracted from a VOT continuum going from the voiced [da] to the voiceless [ta]. For infants that had been exposed to a unimodal distribution the two central tokens of the continuum (ambiguous between [da] and [ta]) were the most frequent, while for infants exposed to the bimodal distribution the two more frequent tokens were the ones close to the endpoints [da]- and [ta]-like, respectively. In agreement with the distributional properties of the input, infants who had heard the unimodal distribution were unable to discriminate the [da]-[ta] distinction at test, whereas infants exposed to the bimodal distribution discriminated successfully between the two plosive categories. Moreover, it has been shown that not only being exposed to a unimodal distribution reduces discrimination, but that being exposed to a bimodal one enhances it (Maye & Weiss, 2003; Maye, Weiss, & Aslin, 2008). These findings indicate that exposure to a unimodal distribution leads to the creation of a single category, around the central tokens of the continuum, while the exposure to a bimodal distribution induces the creation of two categories, one around each end-point. Interestingly, these findings have been replicated in rats (Pons, 2006), highlighting that the sensitivity to distributional regularities arises from a general mechanism that is most likely shared among species.

Furthermore Anderson, Morgan and White (2003) demonstrated that the order of emergence of native-language phonetic categories depends on the frequency and distribution with which exemplars of those categories appear in the input language. English-learning infants of 6½ and 8½ months of age were tested on the discrimination of two non-native consonant contrasts, the coronal Hindi retroflex/dental stop [ʈɜ]-[t̪ɜ] contrast and the dorsal Salish velar/uvular ejective [k'ɜ]-[q'ɜ] contrast. The authors predicted that the decline in discriminability should begin earlier for the non-native coronal contrast, as the most frequent English phonemes are coronal. Accordingly, while 6½ month-olds discriminated both non-native contrasts equally well, 8½-month-old infants were better at discriminating the non-native dorsal contrast [k'ɜ]-[q'ɜ], which corresponds to a lower frequency phonological category in English, than the non-native coronal contrast [ʈɜ]-[t̪ɜ], which corresponds to a higher frequency category in infant's native language. Hence, the results reported by Anderson and collaborators (2003) suggest that the decline in discrimination of non-native contrasts differs as a function of the frequency of native contrasts. The categories corresponding to highly frequent native categories are created earlier, and consequently the decline in the perception of the non-native contrasts that fall close to these categories occurs earlier than the decline of non-native contrasts that fall into less frequent categories. Additional evidence supporting that the frequency of occurrence of phonetic categories influences infants' perception comes from 10-12-month-old French-English bilinguals' discrimination of the /d/-/ð/contrast, which is frequent in English. Although this contrast should be difficult to discriminate by bilingual infants, given the overlap between French and English in these phonemes, the high frequency of the consonants enables the discrimination of the contrast (Sundara et al., 2008).

In addition to frequency of occurrence, it has been revealed that acoustic salience can contribute to the developmental course of category formation. The salience of a contrast depends on the acoustic distance between the sounds tested (the more distant, the more salient) and on the salience of the phonemes themselves (where salient phonemes are more frequent among the world's language repertoires, Liljencrants & Lindblom, 1972 and Maddieson, 1984). Narayan et al. (in press) studied the distinction of nasal place of articulation contrasts, testing 4-5-, 6-8- and 10-12-month-old infants from English and Filipino environments on the discrimination of the [ma]-[na] and [na]-[ŋa] contrasts. Bilabial /m/ and alveo-dental /n/ are more frequent in the world's languages than velar/ŋ/. Additionally, the acoustic distance is larger for the /m/-/n/ contrast than for the /n/-/ŋ/. It was found that the least salient [na]-[ŋa] contrast was only discriminated by the older Filipino infants, while the [ma]-[na] distinction was discriminable by English-learning infants at the three ages tested. Additionally, the failure of English-learning infants in discriminating the fricatives/f/, /θ/ and /ʃ/ has also been attributed to the low acoustic salience of the contrast tested (Eilers et al., 1977).

1.4. The role of task-demands

When reviewing studies that investigate phonetic acquisition it is important to bear in mind the importance of the demands of the task used to test infants' discrimination behavior. Different levels of discrimination performance upon acoustic stimuli can be observed depending on the requirements of the task the infant is confronted with. For instance, there is an apparent contradiction in infants' ability to pick up the difference between a pair of phonemes, depending on whether infants are tested in a purely discrimination task or in a word-learning task. Werker, Fennell, Corcoran and Stager (2002) observed that 14-month-olds failed to react in a word learning switch task to a consonant contrast ([bih]-[dih]), which they were able to perceive in a phonetic discrimination task. However, if 14-month-old infants are tested with a visual choice method instead of the switch task, infants succeed in learning non-words with very similar contrasts ([bin]-[din]) (Yoshida, Fennell, Swingley, & Werker, 2009). Similar task related effects have been found in the domain of infants' categorical perception. On the one hand, several studies demonstrate that infants perceive speech sounds categorically (Eimas & Miller, 1992; Kuhl, 1983), while on the other hand, more recent studies have shown that when tested under the appropriate conditions infants access within-category information to discriminate between stimuli (McMurray & Aslin, 2005).

These results reflect that infants are able to use different levels of detail about the information of the input depending on the requirements of the procedure. Werker & Curtin (2005) accounted for task-demands effects in PRIMIR (Processing Rich Information from Multidimensional Interactive Representations), "an architecture that allows for utilization of different information for different language tasks, with some type of information more easily accessible at different times in development"(p. 213). In PRIMIR, task-demands act as filters, modulating the prominence of different features of the infant's representation. This model allows the infant to perceive categorically and at the same time permits access to subcategorical detail. Thus, PRIMIR proposes a solution to the apparent contradictions in infants' perception abilities.

1.5 Research aims

Summarizing, prior research indicates that the time course of perceptual reorganization is influenced by acoustic biases and by distributional cues present in the input language. Moreover, results advise us to be cautious in interpreting null results, because the task-demands associated to the test paradigms used are sometimes decisive to the outcome of the study. Recent research focuses on other phonetic contrasts, other populations and the development of new procedures, helping to complete the picture of phonetic acquisition. Following on this trend, the present dissertation investigates the role of acoustic salience, language exposure and task-demands in the acquisition of vowels belonging to the native language. We have addressed this question by combining two different behavioral tasks and studying infants from three linguistic populations (Catalan and Spanish monolinguals and Catalan-Spanish bilinguals) at different points in time during the first year of life. The results of this present research are presented separately in two research articles, one exploring the development of vowel asymmetries in monolingual infants and the other investigating the bilingual U-shaped pattern of phonetic perception. This dissertation also presents the adaptation of a new procedure to test infants' discrimination abilities.

1.5.1 Asymmetries in vowel perception

One of the goals of this dissertation is to explore the interplay between acoustic biases and distributional cues in guiding development of speech perception. To this aim, I will explore asymmetries in vowel perception, a phenomenon that has been described in phonetic perception (Polka & Bohn, 2003; Kuhl, Stevens, Hayashi, Deguchi, Kiritani, & Iverson, 2006a; see section 1.1 in this introduction). In general, perceptual asymmetries reveal that some stimuli are perceived as more salient compared to others. In the study of vowel perception, asymmetries have been found to favor peripheral vowels (at least in the contrasts explored). These vowels have been propounded to have a special status which reflects a language-universal bias (Bohn, 2007; Polka & Bohn, 2003). In addition to the relevance of acoustic properties of the signal, distributional cues have been extensively demonstrated to modify the language-universal salience properties of the input, that are dominant in early phases of development (see discussion in the previous section 1.3). There are, however, no studies addressing vowel asymmetries that examine and control for the frequency of occurrence of the vowels tested. The reorganization of the vowel space according to native phonemic categories may induce asymmetries towards the most frequent vowel category, as it will function as a perceptual magnet. However, while acoustic biases are present from birth, the effects of language-experience may need more time to arise.

In order to address this question, the present dissertation investigates the perception of the /i/-/e/ vowel contrast, made up of a peripheral (/i/) and a medial (/e/) vowel, testing infants at three moments of development: Before (4-month-olds), during (6-month-olds) and after (12-month-olds) the process of perceptual reorganization has putatively occurred. The impact of the frequency of occurrence in vowels will be examined by studying Catalan- and Spanish-learning infants, two languages with a different vowel frequency distribution. In Spanish, the medial vowel /e/ is more frequent than peripheral /i/ (Alcina & Blecua, 1975), whereas in Catalan the reverse pattern applies (Rafel, 1980). The goal of this study is to address how the emergence of perceptual asymmetries is influenced by acoustic and distributional factors, and to reveal the time-course of this influence. Knowing which vowel is perceived as the most salient will help us to identify when, during the course of the first year of life, initial biases and distributional cues have an impact on infants' preferences.

1.5.2 The acquisition of phonetic categories in bilingual infants

The second aim of the present dissertation is to test the hypothesis that vowel perception abilities of Spanish-Catalan bilingual infants match those of their monolingual peers. The proposal is that the U-shaped pattern of perception in bilinguals (described in section 1.2.3) is a consequence of familiarization/ preference task demands. To this end the anticipatory eye movement procedure (AEM) developed by (McMurray & Aslin, 2004) will be adapted to study vowel discrimination in 8-month-old Spanish-Catalan bilinguals and Catalan and Spanish monolinguals. The choice of task was motivated by the fact that it does not rely upon novelty preferences. Rather, infants' responses are contingent to each change in the speech stimuli. Therefore, the goal of this experimental series was twofold. First, it sought to assess the effectiveness of the adapted AEM procedure in order to test phonetic discrimination in infants. To do so a mixed group of bilingual and monolingual infants was studied in the discrimination between /e/ and /u/, a contrast that infants are known to discriminate according to previous studies (Sebastián-Gallés & Bosch, 2009). The second, and main objective, will be to explore Catalan-Spanish bilinguals' perceptual abilities. To this end, bilinguals and Catalan and Spanish monolingual infants were tested on the discrimination of the Catalan /e/-/ɛ/ vowel contrast, for which discrimination has only been found so far in Catalan monolinguals (Bosch & Sebastián-Gallés, 2003a). This should reveal if the perceptual abilities of 8-month-old Catalan-Spanish bilinguals differ from monolinguals or whether the U-shaped pattern stems from the requirements of familiarization/preference paradigms.

2. EXPERIMENTAL PART

2.1. Asymmetries in vowel perception during the first year of life

2.1.1. Introduction

Asymmetries are a widespread phenomenon in perception and reveal that some stimuli are perceived as more salient than others. The salience of a stimulus is defined as its capacity to stand out relative to neighboring stimuli. Therefore, differences in salience entail asymmetrical relationships, in which the least salient stimulus is perceived as more similar to the most salient one than is the case for the reverse. This can be illustrated by the asymmetries found in visual perception, where it is easier to detect a long line among short lines than *vice-versa* (Beck, 1974), or a “Q” among “O”s than an “O” among “Q”s (Treisman, 1988; see Figure 1). Similar examples can be found in the auditory modality, where frequency-modulated targets are readily detected among pure-tone distractors, but not in the reverse direction (Cusack & Canyon, 2003).

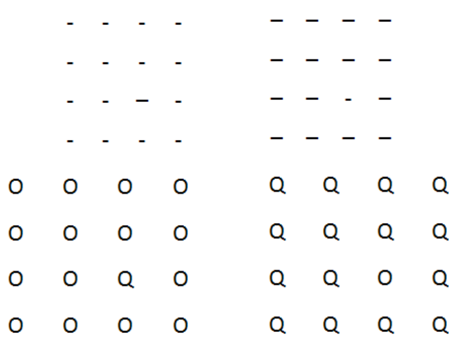

Figure 2.1. Examples of asymmetries in visual perception. The detection of the deviant stimulus is easier in the figures on the left than on the right.

Asymmetrical relationships have also been found in speech perception. For example, in the domain of syntactic acquisition, six-month-old infants show a preference for content over function words: after being habituated to function words, infants recovered their attention to content words but not *vice-versa* (Shi & Werker, 2001). Asymmetries have also been observed at the phonetic level. Polka and Bohn (2003) reviewed several studies reporting asymmetries in infants' vowel perception and found a bias toward the vowel occupying the most peripheral position in the acoustic vocalic space, defined by the formant frequencies of F1 and F2 (for an extension of the peripherality bias to an F1-F2-F3 space, see Best and Faber, 2000). In one of these studies, Polka and Bohn (1996) explored infants' perception of native and non-native vowel contrasts in two stages of development: at 6-8 and 10-12 months of age (during and after perceptual reorganization of the vowel space). Two groups of infants from different language environments (English- and German-learning infants) were tested regarding their discrimination of two vowel contrasts, the English /æ/ - /ɛ/ and the German /y/-/u/ contrast (thus presenting both groups with a native and a non-native contrast). The results indicated that regardless of the language background or age, there was an asymmetry favoring the most peripheral vowel. In other words, the infants' discrimination was more accurate going from /y/ to /u/ for the German /y/-/u/ contrast, and from /æ/ to /ɛ / in the /æ/ - /ɛ/ English contrast, thus reflecting the higher salience of peripheral vowels. These results have been explained in terms of the Natural Referent Vowel hypothesis, which proposes that there is a language-universal bias for peripheral vowels, which have a privileged perceptual status such that they act as perceptual anchors (Bohn, 2007). Schwartz, Abry, Boë, Ménard, and Vallée (2005) proposed that focalization (the convergence of two consecutive formants in a vowel spectrum) is likely to provide the ground for anchor vowels by increasing their perceptual salience. However, Polka and Bohn (2003) stated that "the experience listening to one's native language serves to fine-tune these initial biases such that asymmetries will be maintained, further enhanced or reduced in accordance with the structure of native vowel categories" (p. 227). If the vowels tested form a phonemic contrast in the native language, it is predicted that the asymmetry will decrease. Otherwise, the bias towards peripheral vowels would remain later in life.

A similar pattern of asymmetries has also been found in consonant perception. Kuhl and colleagues (2006a) tested English-learning and Japanese-learning infants aged 6-8 and 10-12 months old on their discrimination of the /r/-/l/ English contrast. Irrespective of the age and the native language, infants' discrimination performance was better when the direction of change went from [la] to [ra] than from [ra] to [la]. The authors suggested that these asymmetries might reflect a bias either in general auditory perception or derived from linguistic experience.

In addition to acoustic biases in speech perception, another source of asymmetries may be distributional cues. Researchers have established that the perceptual reorganization of phonetic categories undergone by infants in the first year of life is based on a bottom-up analysis of speech sounds. For instance, Maye et al. (2002) showed that infants are sensitive to the frequency distribution of speech sounds in their language and use this to build up their native phonetic categories. Furthermore, the Native Language Magnet theory (Kuhl et al., 1992; Kuhl et al., 2008) proposes that phonetic categories are internally structured following distributional cues. In the resultant structure the category prototype induces the Perceptual Magnet Effect, an asymmetrical relationship in which a non-prototypical stimulus is perceived as being more similar to the prototype than *vice-versa*.

The influence of distributional cues extends to the course of perceptual reorganization. Anderson et al. (2003) demonstrated that the order of emergence of native-language phonetic categories depends on the frequency of occurrence with which exemplars of those categories appear in the input. English-learning infants of 6½ and 8½ months of age were tested on the discrimination of two non-native consonant contrasts: the coronal Hindi retroflex/dental stop [ʈɜ]-[t̪ɜ] contrast and the dorsal Salish velar/uvular ejective [k'ɜ]-[q'ɜ] contrast. Results indicated that 6½-month-olds discriminated both non-native contrasts equally well. However, 8½-month-old infants were better at discriminating the non-native dorsal contrast [k'ɜ]-[q'ɜ], which corresponds to a lower frequency phonological category in English, than they were at the non-native coronal contrast [ʈɜ]-[t̪ɜ], which corresponds to a higher frequency category in the infants' native language. These results suggest that high-frequency categories are created earlier and, consequently, that the decline in discrimination of non-native contrasts corresponding to native high-frequency contrasts also occurs earlier.

Additional evidence for the importance of the frequency of appearance is found in bilingual phonetic discrimination. Bilingual infants (compared to monolingual infants) have been reported to show a delay in discriminating a pair of acoustically-close phonemes (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009). However, Sundara et al. (2008) explored the discrimination of the English coronal stop /ð/-/d/ contrast, which is acoustically close but also highly frequent. The results revealed that French-English bilinguals discriminated the contrast at the same age as monolingual infants, indicating that the higher frequency of the coronal contrast explained why bilingual infants could discriminate the acoustically-close consonant contrast.

However, it has recently been pointed out that salience also plays a role in the developmental process of category formation. Narayan et al. (in press) observed that differentiation of less salient contrasts was accomplished later than the discrimination of more salient ones. Infants at different ages (4-5, 6-8 and 10-12 months of age) and from two different language environments (English and Filipino) were tested on their capacity to discriminate the nasal alveo-dental/velar [na]-[ŋa] and the nasal bilabial/alveo-dental [ma]-[na] contrast. The salience of a contrast is determined by the salience of the phonemes tested (salient phonemes are among the most frequent in the world's language repertoires[1]) and by the acoustic distance between the phonemes tested (the more distant, the higher salience). Of the contrasts tested, [na]-[ŋa] is the least salient, as the consonants are acoustically close and /ŋ/ is less frequent in the repertoire of the world's languages than are the other nasal consonants, /m/ or /n/.

The results showed that the native salient [ma]-[na] contrast was discriminated by English-learning infants at all ages. However, the Filipino [na]-[ŋa] distinction was not discriminated by either English-learning infants (regardless of age) or Filipino-learning infants at 6-8 months of age. It was not until 10-12 months of age that Filipino-learning infants were able to discriminate the [na]-[ŋa] native contrast. Thus, these results provide evidence that in addition to language experience, salience also affects the course of perceptual reorganization during the first year of life, such that less salient contrasts need more exposure to the language in order to be acquired.

The studies reviewed above indicate that infants are sensitive to both acoustic biases and distributional cues. However, while acoustic salience effects are seen from the beginning of life, the effects of frequency distribution appear later. To our knowledge, no study has addressed the temporal dynamics of the relevance of these two factors in the establishment of native language phonetic categories. The goal of the present study is therefore to explore the role of acoustic salience and distributional cues in infants' perception of native vowels. This was achieved by analyzing the performance of Catalan- and Spanish-learning infants aged 4, 6 and 12 months old (before, during and after the perceptual reorganization) on their discrimination of the /e/-/i/ vowel contrast. The different vowel frequency distribution of the Catalan and Spanish languages allows the frequency of occurrence of each vowel to be controlled for. In Spanish the medial vowel /e/ is more frequent than the more peripheral vowel /i/ (Alcina & Blecua, 1975), whereas in Catalan the more peripheral vowel /i/ is also more frequent than vowel /e/ (Rafel, 1980) (see Table 1). The acoustic salience of /i/ is predicted both by the peripherality bias (Polka & Bohn, 2003) and because it is more frequent than /e/ in the world's languages (Maddieson, 1984). Thus, it would be expected that 4-month-olds (before perceptual reorganization) will show asymmetries favoring the more salient vowel (/i/). Later, as infants gain experience with their native language, these asymmetries towards the peripheral vowel might be modulated by the frequency of occurrence of the vowels in each language. If this is true, then infants should either show no asymmetries, as /e/ and /i/ form a phonemic contrast in both Catalan and Spanish, or shift their asymmetries towards the more frequent category vowel (/e/ for Spanish-learning and /i/ for Catalan-learning infants).

Table 1. Frequency of occurrence for vowels /i/ and /e/ in Spanish (Alcina & Blecua, 1975) and in Catalan (Rafel, 1980). The percentage is calculated according to the number of vowels in the language (5 in the case of Spanish and 8 for Catalan). The table also shows the percentage of world languages which include vowels /i/ and /e/ in their phonetic repertoire (Maddieson, 1984).

Frequency of occurrence	**/i/**	**/e/**
Spanish	18%	27%
Catalan	14%	5%
World's languages	91.5%	37.2%

2.1.2. Experiment 1: before perceptual reorganization

In this experiment the youngest infants (4-month-olds) from both Catalan and Spanish environments were tested on their ability to discriminate the /e/-/i/ contrast. Since infants at 4 months of age perceive vowel sounds in a language-universal mode, no differences were expected between Catalan- and Spanish-learning groups. However, if infants are influenced by the highest salience of vowel /i/, the discrimination of the /e/-/i/ contrast would be easier when the direction of the change goes from the medial vowel (/e/) to the peripheral vowel (/i/) rather than vice versa (from /i/ to /e/).

2.1.2.1 Method

Participants. Participants were 48 full-term 4-month-old infants: 24 Catalan-learning (M=120 days, range=104 to 138 days) and 24 Spanish-learning (M=124 days, range=106 to 137 days). All were full-term, healthy and had no history of ear infections according to the parents' report. Fifteen additional infants participated in the study but were excluded from the analysis due either to crying or fussiness (n=10; 3 Catalan-learning, 7 Spanish-learning), experimental error (n=1; Spanish-learning) or failure to habituate (n=4; 2 Catalan-learning, 2 Spanish-learning).

Participants were recruited by visiting new mothers at the Hospital Sant Joan de Déu and the Clínica Sagrada Família (Barcelona). Although in Barcelona both Catalan and Spanish are spoken (indeed, the great majority of the population is bilingual and both languages are taught in school), the infants participating in this study were growing up in monolingual families. A detailed language questionnaire (Bosch & Sebastián-Gallés, 2001) was administered and only infants with less than 15% exposure to the other language were included in the sample. Parental consent was acquired before running the experiment.

Stimuli. A Spanish-Catalan bilingual female speaker produced multiple tokens of the syllables [bel] and [bil]. The speaker produced the tokens with different infant-directed speech intonation patterns. Twenty tokens were selected, 10 for the habituation phase (5 [bel] and 5 [bil]) and 10 for the test phase (5 [bel] and 5 [bil]). To minimize acoustic differences across categories, tokens were matched for syllable duration, pitch and intensity, measured with Praat (Boersma & Weenink, 2005). Table 2 shows the main acoustic characteristics of the stimuli.

Table 2. Acoustic measurements. F1, F2 and F3 were calculated on the mid portion of vowels.

Habituation	Token	Duration (ms)	AvgPitch	Pitch Range	F1 (Hz)	F2 (Hz)	F3 (Hz)	Intensity (dB)
[bel]	1	0.79	213	133	568	2388	3086	70.00
	2	0.76	217	72	666	2233	3018	69.99
	3	0.89	288	341	788	2459	3179	69.99
	4	0.97	251	223	633	2578	3303	70.00
	5	0.88	313	206	688	2435	2884	69.99
	Avg.	*0.86*	*256*	*195*	*668*	*2419*	*3094*	*70.00*
	SD	*0.07*	*39*	*91*	*72*	*112*	*142*	*0.00*
[bil]	1	0.77	216	122	268	2817	3374	69.99
	2	0.77	226	55	346	2611	3223	70.00
	3	0.89	290	334	454	2285	2860	69.99
	4	0.97	271	230	378	2459	3126	70.00
	5	0.87	324	216	368	2749	3376	69.99
	Avg.	*0.85*	*265*	*191*	*363*	*2584*	*3192*	*70.00*
	SD	*0.08*	*40*	*96*	*60*	*194*	*191*	*0.00*
Test	Token	Duration (ms)	AvgPitch	Pitch Range	F1 (Hz)	F2 (Hz)	F3 (Hz)	Intensity (dB)
[bel]	1	0.73	216	84	649	2288	2988	69.99
	2	0.68	217	106	548	2381	3099	70.00
	3	0.91	324	319	798	2400	3263	69.99
	4	0.89	316	206	651	2495	3127	69.99
	5	0.98	256	*215*	614	2549	3358	70.00
	Avg.	*0.84*	*266*	*186*	*652*	*2423*	*3167*	*70.00*
	SD	*0.11*	*47*	*85*	*82*	*91*	*130*	*0.00*
[bil]	1	0.75	228	70	362	2619	3217	69.99
	2	0.67	222	111	280	2802	3290	70.00
	3	0.96	290	346	460	2251	2993	69.99
	4	0.91	314	197	361	2723	3214	70.00
	5	1.00	270	*215*	374	2828	3315	70.00
	Avg.	*0.86*	*265*	*188*	*367*	*2645*	*3206*	*70.00*
	SD	*0.12*	*36*	*95*	*57*	*210*	*113*	*0.00*

Procedure. We implemented a visual habituation procedure, a task widely used to study infants' discrimination abilities. This has been described as salience-sensitive (Turk-Browne, Scholl, & Chun, 2008) and is appropriate for testing the age range under study. The visual habituation procedure was implemented as described in Werker et al. (1998). The presentation of stimuli was controlled with the Habit software (Cohen, Atkinson, & Chaput, 2004). The experimenter began each trial when the infants fixed their gaze on an attention getter, a blue expanding flower. In each trial, infants repeatedly heard tokens of the same syllable (either [bel] or [bil]), presented contingently to an image of a black-and-white checkerboard. The experimenter recorded infants' looking times by pressing a key. Looking times were computed over a window of three trials and the criterion of habituation was set to a decrement of 40% for the longest group of three consecutive trials.

Half the infants were habituated to the syllable [bel] and were presented with [bil] tokens in the switch trial and with [bel] tokens in the same trial; the other half were habituated to [bil] with the reverse pattern of same ([bel]) and switch trials ([bil]). Same and switch trials were counterbalanced across participants. As infants tend to look longer at novel stimuli, they were expected to increase their looking times on switch trials compared to same trials. However, it should be noted that a failure to dishabituate to switch trials may not imply that infants did not notice the difference between test trials, but rather that the change was not relevant enough to regain the infant's attention (Wang & Baillargeon, 2006).

For the habituation phase three trials with a total duration of 14 s were created for each vowel category. Each trial contained 7 tokens: the five selected tokens were presented once and two of them (chosen at random) were repeated, with a stimulus interval of approximately 1 s. Test trials had the same characteristics as habituation ones, but there was only one trial for each vowel.

If the infant looked for less than 1 s on any given trial, the trial was repeated. If this happened in test trials the infant was not included in the analysis. Infants were also excluded if they failed to habituate in 24 trials, the maximum number of habituation trials allowed.

In order to assess the infant's task engagement the experiment began with a pretest and finished with a posttest trial. These consisted of a movie of a spinning waterwheel presented at the same time as tokens of a sine wave tone.

Off-line coding. Infants' looking times were coded offline by a trained coder who was unaware of which test trial was a same or a switch trial, and also of the syllable presented in each trial. Trials were coded frame-by-frame (1 frame = 40 ms). An additional coder re-scored 25% of the videos in order to assess inter-observer reliability. The Pearson correlation coefficient between coders was .98.

Set-up and apparatus. During the experiment the infant was seated on an infant seat. The caregiver was also present in the room, sitting silently behind the infant. Testing took place in a dimly lit, sound-attenuated, 178 by 150 cm laboratory room, with the screen situated 75 cm from participants. Two stereo loudspeakers (Philips Multimedia Speaker System) hidden behind the screen played the stimuli at 65 ± 5 dB SPL. The images were reproduced through a Mitsubishi XL8U projector and projected onto a 99 by 86 cm screen. The presentation of both the auditory and visual stimuli was controlled with the Habit software (Cohen et al., 2004) using a Power Mac G5. Infants were recorded with a Canon MV750i video camera mounted under the screen, while the experimenter ran the experiment from outside the room, following the infants' eye gaze through a Panasonic BT-S1460Y TV monitor.

2.1.2.2. Results and discussion

For each infant, mean looking times were computed for the pretest and posttest trials and for the same and switch trials. A preliminary 2 (language: Spanish- vs. Catalan-learning infants) by 2 (test: pretest vs. posttest) repeated-measures ANOVA was carried out to determine if there were any language-related differences in infants' task engagement. There were no significant effects of language or test ($F(1,46)=0.582$, $p=0.45$), indicating that both groups of infants maintained their interest during the experimental session. The main analysis consisted of a 2 (language: Spanish vs. Catalan) by 2 (direction of change: /e/ to /i/ vs. /i/ to /e/) by 2 (trial type: same vs. switch) ANOVA. This revealed a main effect of trial type ($F(1,44)=7.846$, $p=0.007$), indicating that infants looked longer on switch than on same trials ($t(47)=-2.53$, $p=0.014$). There was also an interaction between trial type and direction of change ($F(1,44)=12.49$, $p<0.001$), illustrating that only infants tested in the direction of change from /e/ to /i/ looked significantly longer on switch than on same trials ($t_{/e/to/i/}(23)=-4.19$, $p<0.001$; $t_{/i/to/e/}(23)=0.577$, $p=0.569$). Twenty-one of the 24 infants tested in each direction of change looked longer on switch trials when the direction of change was from the medial to the peripheral vowel. In contrast, when the direction of change was from the peripheral to the medial vowel only 8 out of 24 infants looked longer on switch trials. There were no effects of language. The results according to language and direction of change are plotted in Figure 1.

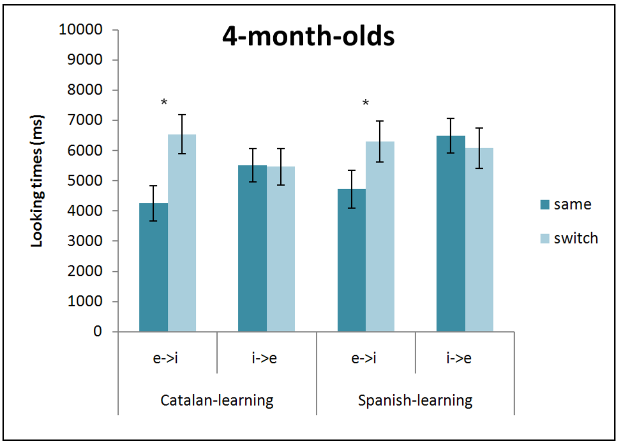

Figure 2.2. Four–month-olds' mean looking times on same and switch trials for each language group and each direction of change (from /e/ to /i/ and from /i/ to /e/). The figure shows that both Catalan and Spanish-learning infants looked significantly longer on switch trials only when the direction of change goes from the vowel /e/ to the vowel /i/. The bars indicate the standard error.

As expected, the results from Experiment 1 revealed no differences between Catalan- and Spanish-learning infants, thus supporting the notion that 4-month-olds are at a language-universal stage. More importantly, infants showed a clear asymmetry towards vowel /i/, indicating that the peripheral vowel /i/ is more salient than the medial vowel /e/. Infants perceived the syllables containing the vowel /e/ as being more similar to the tokens containing the vowel /i/ than the other way around, regardless of the language spoken in the infants' environment. These results highlight the influence of acoustic salience on infant perception, which was previously indicated by the language-universal bias towards peripheral vowels proposed by Polka and Bohn (2003) and by Narayan and collaborators (in press).

2.1.3. Experiment 2: during perceptual reorganization

In this second experiment, 6-month-old infants from both Catalan and Spanish environments were tested on their ability to discriminate the same /e/-/i/ contrast used in the previous experiment. At 6 months infants have already started to reorganize their vowel categories according to the language they are exposed to (Kuhl et al., 1992), and therefore the effects of vowel frequency distribution may arise. The formation of native vowel categories could lead infants to show no asymmetries, as both vowels are native phonemes. Conversely it might lead infants to show an asymmetry that favors the more frequent vowel of the contrast tested, which would act as the prototype. Thus, the discrimination of the contrast should be easier when the direction of the change is from /i/ to /e/ for Spanish-learning infants and from /e/ to /i/ for Catalan-learning infants.

Method

The procedure, stimuli and apparatus of Experiment 2 were identical to those in Experiment 1, with the exception that in this experiment (and also in Experiment 3) the infant was seated on their caretaker's lap, who was listening to music through Climax 14P headphones, thus avoiding any interference with the infant's behavior. The rest of the set-up was the same as that described in Experiment 1.

Participants. Participants were 48 full-term 6-month-old infants, 24 Catalan-learning (M=182 days, range=167 to 200 days) and 24 Spanish-learning (M=185 days, range=163 to 199 days). All were full-term, healthy and had no history of ear infections according to the parents' report. Thirteen additional infants participated in the study but were excluded from the analysis due either to crying or fussiness (n=9; 4 Catalan-learning, 5 Spanish-learning), parental interference (n=2, Spanish-learning) or failure to habituate (n=2; 1 Catalan-learning and 1 Spanish-learning).

2.1.3.1. Results and discussion

As in Experiment 1, mean looking times of each infant were obtained for pretest and posttest trials and for switch and same trials. A preliminary 2 (language: Spanish- vs. Catalan-learning infants) by 2 (test: pretest vs. posttest) repeated measures ANOVA was performed to ensure that infants from both language groups were engaged in the task. There were no effects of language or test ($F(1,46)=0.119$, $p=0.73$), indicating that both groups of infants were paying equivalent attention over the experimental session. A 2 (language: Spanish vs. Catalan) by 2 (direction of change: /e/ to /i/ vs. /i/ to /e/) by 2 (trial type: same vs. switch) repeated measures ANOVA was then carried out to test whether there were language group or direction of change differences in infants' looking times on same and switch trials. This indicated a main effect of trial type ($F(1,44)=7.603$, $p=0.008$), showing that infants looked significantly longer on switch compared to same trials ($t(47)=-2.73$, $p=0.009$). The interaction of trial type and direction of change was marginal ($F(1,44)=3.575$, $p=0.065$). Subsequent planned comparisons revealed that only infants tested in the direction of change from /e/ to /i/ looked significantly longer on switch than on same trials ($t_{/e/to/i/}(23)=-3.250$, $p=0.004$; $t_{/i/to/e/}(23)=-0.648$, $p=0.524$). There were no effects of language, suggesting that Catalan- and Spanish-learning infants followed the same pattern of preferences. Nineteen of the 24 infants tested for each direction of change looked longer on switch trials when the direction of change was from /e/ to /i/. When the direction of change was from /i/ to /e/, 16 infants looked longer on switch than on same trials.

Planned comparisons were carried out for each language group and direction of change in order to explore whether language experience was influencing the infants' behavior. The results are plotted in Figure 2. Replicating the results obtained with 4-month-olds, 6-month-old Catalan-learning infants looked significantly longer on switch trials than on same trials when the direction of the change was from /e/ (the medial and less frequent vowel in Catalan) to /i/ (the most peripheral and more frequent vowel in Catalan) than *vice-versa* ($t_{/e/to/i/}(11)=-3.029$, $p=0.011$; $t_{/i/to/e/}(11)=-0.615$, $p=0.551$). However, 6-month-old Spanish-learning infants showed no differences in looking times on same and switch trials for either direction of change ($t_{/e/to/i/}(11)=-1.775$, $p=0.104$; $t_{/i/to/e/}(11)=-0.296$, $p=0.773$). A 2 (age: 4- vs. 6-month-olds) by 2 (direction of change: /e/ to /i/ vs. /i/ to /e/) by 2 (trial type: same vs. switch) repeated measures ANOVA was then carried out to test whether there were age effects on the behavior of Spanish-learning infants. This revealed a main effect of trial type ($F(1,44)=4.534$, $p=0.038$) and an interaction between trial type and direction of change ($F(1,44)=6.21$, $p=0.016$). There was also a marginal main effect of age ($F(1,44)=3.105$, $p=0.084$), suggesting that 6-month-olds' looking times were shorter than at 4 months of age. There was no interaction between age and trial type ($F(1,44)=0.059$, $p=0.807$) or between age, direction of change and trial type

(F(1,44)=0.489, p=0.487), indicating that Spanish-learning infants have not changed their preference for vowel /i/ from 4 to 6 months of age.

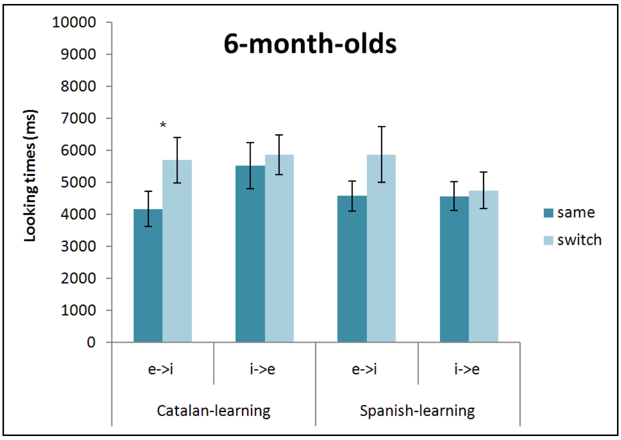

Figure 2.3. Six–month-olds' mean looking times on same and switch trials for each language group and each direction of change (from /e/ to /i/ and from /i/ to /e/). The figure shows that Catalan-learning infants looked significantly longer on switch trials when the direction of change goes from the vowel /e/ to the vowel /i/. The bars indicate the standard error.

The results of Experiment 2 indicate that 6-month-old Catalan- and Spanish-learning infants displayed the same pattern of asymmetries. Replicating the results obtained at 4 months of age the peripheral vowel /i/ was perceived as more salient than the medial vowel /e/. However, it should be noted that planned comparisons revealed that Spanish-learning infants did not show a statistically significant discrimination of the /e/-/i/ contrast in any direction of change. These results suggest that the effects of perceptual reorganization following experience with language may be underway but not yet observable. To assess this possibility we studied a group of 12-month-old infants, who are well beyond the perceptual reorganization of the vowel system.

2.1.4. Experiment 3: after perceptual reorganization

As has been previously discussed, perceptual reorganization of the vowel space is driven by both salience and distributional factors. However, although there is evidence that 6-month-olds have already reorganized their vowel categories according to their native language (Kuhl et al., 1992), the results of Experiment 2 did not indicate an effect of distributional cues. It is possible that more exposure to their native language is needed for frequency of occurrence effects to arise. Hence we tested 12-month-olds, this being an age when the effects of specific language experience are evident.

Method

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

Participants. Participants were 48 full-term 12-month-old infants, 24 Catalan-learning (M=356 days, range=346 to 374 days) and 24 Spanish-learning (M=354 days, range=338 to 376 days). All were full-term, healthy and had no history of ear infections according to the parents' report. Ten additional infants participated in the study but were excluded from analysis due either to crying or fussiness (n=7; 3 Catalan-learning, 4 Spanish-learning), experimental error (n=2; Catalan-learning) or repetition of one test trial (n=1; Spanish-learning).

2.1.4.1. Results and discussion

Mean looking times were computed for the pretest and posttest trials and for the same and switch trials. A preliminary 2 (language: Spanish- vs. Catalan-learning infants) by 2 (test: pretest vs. posttest) repeated-measures ANOVA was carried out to determine whether there were any language-related differences in the infants' task engagement. This revealed no significant effects of language or test ($F(1,46)<0.001$, $p=0.975$). A 2 (language: Spanish vs. Catalan) by 2 (direction of change: /e/ to /i/ vs. /i/ to /e/) by 2 (trial type: same vs. switch) repeated measures ANOVA was then performed to test whether there were language or direction-of-change differences in infants' looking times on same and switch trials. Here there was a main effect of trial type ($F(1,44)=18.07$, $p<0.001$), indicating that infants looked significantly longer on switch than on same trials ($t(47)=-3.91$,$p<0.001$). Crucially, there was a significant triple interaction between trial type, direction of change and language ($F(1,44)=10.66$, $p=0.002$). Subsequent t-tests revealed that Catalan-learning infants looked significantly longer on switch than on same trials when the direction of change went from /e/ to /i/ ($t_{/e/to/i/}(11)=-2.63$, $p=0.023$; $t_{/i/to/e/}(11)=-0.35$, $p=0.731$). In contrast, Spanish-learning infants looked significantly longer on switch trials when the test trial changed from /i/ to /e/ rather than when the change was from /e/ to /i/ ($t_{/e/to/i/}$ $(11)=-0.62$, $p=0.543$; $t_{/i/to/e/}$ $(11)=-5.97$, $p<0.001$). Eight of the 12 Catalan-learning infants tested in the /e/ to /i/ direction looked longer on switch trials, whereas only 4 of the 12 tested in the opposite direction showed this novelty effect. Regarding Spanish-learning infants, 7 out of 12 looked longer on switch trials when these involved the presentation of the /i/ vowel, whereas all 12 infants tested in the /i/ to /e/ direction looked longer on switch trials. A main effect of language was also present (F(1,44)=6,46, p=0.011), revealing that Catalan-learning infants' looking times were significantly longer compared to those of Spanish-learning infants (t(47)=2.49, p=0.015). The results for each language group and direction of change are plotted in Figure 3.

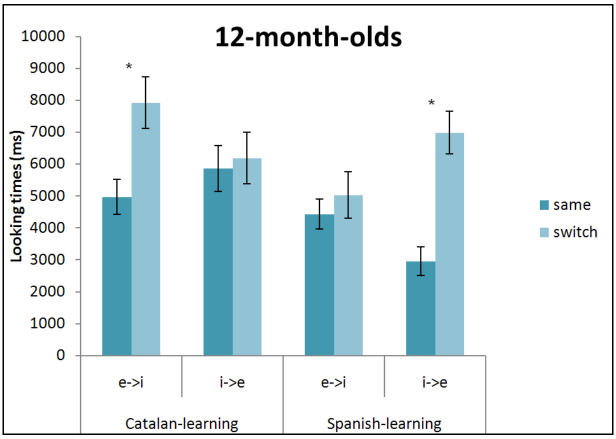

Figure 2.4. Twelve–month-olds' mean looking times to same and switch trials for each language group and each direction of change (from /e/ to /i/ and from /i/ to /e/). The figure shows that Catalan-learning infants looked significantly longer to switch trials when the direction of change went from the vowel /e/ to the vowel /i/ and that Spanish-learning infants looked significantly longer to switch trials when the direction of change went from /i/ to /e/. The bars indicate the standard error.

The results of Experiment 3 revealed that 12-month-old Catalan-learning infants showed an asymmetry towards the vowel /i/, in keeping with the results obtained at 4 and 6 months of age. However, Spanish-learning infants at this same age dishabituated to the most frequent vowel /e/ but not to the less frequent /i/. To evaluate developmental changes a 3 (age: 4-, 6- and 12-month-olds) by 2 (direction of change: /e/ to /i/ vs. /i/ to /e/) by 2 (trial type: same vs. switch) repeated measures ANOVA was carried out for each group of infants. The results for Catalan-learning infants revealed a main effect of trial type ($F(1,66)=15.56$, $p<0.001$), indicating that infants looked longer on switch than on same trials. There was also an interaction between trial type and direction of change ($F(1,66)=10.74$, $p=0.002$), confirming the higher salience of the more peripheral vowel of the contrast across the three age ranges. Importantly, Catalan-learning infants did not show any interaction with age (all $F<1$).

The ANOVA for Spanish-learning infants also showed a main effect of trial type ($F(1,66)=18.22$, $p<0.001$) and an interaction between trial type and age ($F(1,66)=3.77$, $p=0.028$), revealing that only 12-month-old infants looked significantly longer on switch than on same trials. Importantly, there was a triple interaction of trial type, direction of change and age ($F(1,66)=8.74$, $p<0.001$), indicating that only 4-month-olds in the /e/ to /i/ direction of change, and 12-month-olds in the /i/ to /e/ direction of change looked significantly longer on switch than on same trials. The present results reveal a change in Spanish-learning infants' vowel preferences. Before perceptual reorganization takes place, infants are attracted by acoustically salient vowels. However, once they have reorganized their vowel categories the most salient vowel is the most frequent one in their language. In contrast, Catalan infants did not show this developmental change, as in their case both frequency of occurrence and acoustic salience corresponded to the same vowel.

2.1.5. General discussion

The results of the present study confirm that both acoustic salience and distributional cues have an effect on infants' vowel perception. Furthermore, the current findings suggest a different timing of influence for each factor. Acoustic saliency seems to apply earlier and while perceptual reorganization is taking place, as exemplified by infants' preference for vowel /i/ at both 4 and 6 months of age. However, as infants gain experience with their native language, a shift in the salience of vowels can be observed: for example, 12-month-old Spanish-learning infants dishabituate to vowel /e/ but not to vowel /i/. These results indicate that the most frequent vowel increases in salience during the first year of life. Consequently, the developmental pattern of asymmetries in vowel perception differs as a function of the language the infant is acquiring. Catalan-learning infants, for whom /i/ is both more frequent and more acoustically salient, show a preference for this vowel at the three ages tested. Conversely, Spanish-learning infants show a preference for the acoustically salient vowel /i/ at 4 and 6 months of age, but at 12 months the preference shifts toward the more frequent vowel /e/.

In light of the results obtained, the asymmetries revealed by Kuhl and collaborators (2006) can be interpreted as being driven by acoustic factors. The ages tested in that study were 6-8 and 10-12 months, that is, before and during the perceptual reorganization for consonant contrasts. Thus, it might be that the alveolar trill makes /r/ more acoustically salient than /l/. Given the results obtained in the present study we predict that infants would need more language exposure to show an effect of distributional cues at 10-12 months of age, which explains why, in the study by Kuhl and colleagues (2006), there were no language differences (between English- and Japanese-learning infants). The prediction for older English-learning infants would be a later shift in their preferences to the consonant /l/, which occurs more often than /r/ in English (Kessler, 1997).

The results reported here also confirm the sensitivity of visual habituation procedures for revealing infants' biases for salient information. However, this contrasts with the results obtained by Narayan and collaborators (in press), who used the same visual habituation procedure. Even though the consonants tested by Narayan and colleagues (in press) differed in acoustic saliency (with the Filipino [na] being much more salient than [ŋa]), the authors did not report any asymmetries, such that Filipino-learning 10-12-month-olds discriminated the [na]-[ŋa] contrast equally well in both directions of change. The discrepancy between these and our results cannot be accounted for by the different function of vowels and consonants (see Bonatti, Nespor, Peña, & Mehler, 2005; Nespor, Peña, & Mehler, 2003; Toro, Nespor, Mehler, & Bonatti, 2008) because, as noted above, asymmetries in consonant perception have also been reported (Kuhl et al., 2006). It might be that other acoustic features of the /n/-/ŋ/ contrast overrides the difference in salience. Further research is needed to explain why asymmetries may arise with some phonetic categories but not with others.

Importantly, the present results do not support the prediction by Polka and Bohn (2003) that asymmetries will diminish over development if the vowel contrast is phonemic in the language tested. Indeed, our results for 12-month-old infants are striking given that the vowels tested contrast phonemically in both Catalan and Spanish. As such, the formation of native categories would predict that both vowels should be discriminated equally well. However, the infants' responses revealed that one of the vowels tested was more salient than the other.

Our results also differ from what would be expected according to the proposal that the first formant (F1) is a salient dimension for infants' vowel perception. It has recently been demonstrated (Curtin, Fennell, & Escudero, 2009) that 15-month-old infants tested on a word-learning task were able to learn two words that differ by only one vowel sound. However, infants only succeeded when the vowel pair tested differed in the F1 dimension, but not if vowels changed only in F2. The authors conclude that F1 is the most salient cue for vowels. Additional support for the salience of F1 comes from evidence that infants were more sensitive to word mispronunciations involving vowel height (F1) and backness (F2) rather than vowel roundedness (F3) (Mani, Coleman, & Plunkett, 2008). Given that F1 is a relevant dimension for infants' perception, these results would predict that, since the stimuli used in the current study differ in F1, infants should discriminate the vowels tested accurately. However, the present results indicate that infants display an asymmetry towards the most salient vowel, instead of discriminating both equally well. However, it should be noted that the discrepancies between the word-learning studies and the results reported here are likely due to differences in task-demands, as well as to the infants' developmental stage. Werker & Curtin (2005) suggested that infants use a different representation of their knowledge depending on task demands. Specifically, infants access different aspects of their language knowledge to respond to discrimination and word-learning tasks. For instance, Werker et al. (2002) observed that 14-month-olds failed to react in a word-learning switch task to a consonant contrast ([bih]-[dih]) that they were able to perceive in a phonetic discrimination task. However, when infants were tested with a visual choice method instead of the switch task, 14-month-olds were successful with very similar contrasts ([bin]-[din]) (Yoshida et al., 2009). Thus, it is possible that both older infants, with an expanded vocabulary, and even 12-month-olds tested with another task would not show asymmetries in vowel perception.

To sum up, the goal of the present study was to investigate the temporal dynamics of acoustic biases vs. distributional cues as regards the establishment of native vowel categories. The results showed an extended prevalence of acoustic biases: it was not until 12 months of age that significant effects of distributional cues were observed. Although the vowels tested formed a phonetic contrast in both languages, the observed asymmetries indicated that the acoustic bias for peripheral vowels was present until distributional information goes against it.

2.2 The acquisition of phonetic categories in bilingual infants: New data from an anticipatory eye movement paradigm

2.2.1. Introduction

In the early months of life, infants are able to discriminate many of the phonetic contrasts in the world's languages (Eimas et al., 1971). However, by the end of their first year, their ability to discriminate many non-native contrasts has declined (Anderson et al., 2003; Best & McRoberts, 2003; Kuhl et al., 1992; Werker & Tees, 1984), while their perception of native contrasts has improved (Aslin & Pisoni, 1980; Kuhl, Stevens, Hayashi, Deguchi, Kiritani, & Iverson, 2006b; Polka et al., 2001; Sundara et al., 2006; Tsao et al., 2006). This previous research has been conducted exclusively with monolingual infants but, although bilingual homes are clearly prevalent today, studies of acquisition in bilinguals are scarcer and are yet to present a clear picture.

One of the earliest studies to explore the phonetic capabilities of bilingual infants was undertaken by Bosch and Sebastián-Gallés (2003b). The study examined infants from three different linguistic environments: Catalan monolingual, Spanish monolingual and Catalan-Spanish bilingual. Discrimination of the Catalan contrast /ɛ/-/e/, which is not present in Spanish, was assessed using a familiarization-preference procedure. The results replicated the language-general mode of perception at 4 months of age, revealing that all three groups of infants were equally able to distinguish the phonetic contrast. Likewise, the study showed that the sensitivity to non-native contrasts subsequently declines: so while 8-month-old Catalan monolinguals could still discriminate the contrast, 8-month-old Spanish monolinguals could not. Interestingly, a specific developmental pattern was found in bilinguals: at 4 months, these infants could distinguish the contrast; at 8 months they performed the discrimination task unsuccessfully, but recovered the discriminatory response at 12 months of age. The same pattern has also been observed for a Catalan-specific consonant contrast (/s/–/z/), and a common Catalan and Spanish vowel distinction (/o/-/u/), though not for the /e/-/u/ contrast. The latter, although common, is acoustically more distant, and 8-month-old bilinguals were able to discriminate the contrast (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009).

However, other studies exploring the phonetic development of bilinguals have not replicated these Catalan-Spanish findings. Burns et al. (2007) and Sundara et al. (2008) observed that English-French bilingual infants were able to discriminate all the consonant contrasts presented to them at all ages. Thus, an explanation of the behavior of Spanish-Catalan bilinguals cannot rely solely on their exposure to bilingual input, since French-English bilinguals should also have presented certain difficulties in discriminating phonetic contrasts. Yet, neither can these conflicting results be attributed to the use of different experimental procedures, since were this to be the case, the reason why 8-month-old Catalan monolinguals performed the task successfully while 8-month-old Catalan-Spanish bilinguals did not should be explained.

An explanation for these findings might lie in the differences in the input received by Catalan-Spanish and French-English bilinguals respectively. One crucial difference between the two language pairs is the number of cognates they share. An analysis of noun forms in the respective versions of the McArthur-Bates inventory shows that around 66% of words in Spanish and Catalan are cognates, while for French and English the number falls to 33% (Sebastián-Gallés, Albareda-Castellot, & Pons, under review). Thus, there is clearly an initial difference in the input received by infants in these respective studies in terms of the percentage phonological overlap, i.e., much more marked in the case of Spanish-Catalan bilinguals than for their English-French counterparts.

Because of their nature, cognates tend to sound very similar, albeit in most instances not identical (compare, by way of example, the pronunciation of "chocolate" in English, French, Catalan and Spanish: /tʃɒklət/, /ʃɔkɔla /, /ʃukulatə/ and /tʃokolate/). In common with dialectal variation, vowel differences play a key role in these differences (see, for example, Thomas, 2001), for a description of the dialectal variation in American English). Thus, the input to which Catalan-Spanish bilingual are exposed includes a high percentage of words that differ fundamentally in terms of vowel sounds. In order to learn new words, a highly adaptive strategy for Catalan-Spanish bilingual infants involves focusing on consonant, rather than vowel, sounds. Returning to the previous example, a Catalan-Spanish bilingual infant might treat /ʃukulatə/ and /tʃokolate/ as varieties of the same word (/ʃVkVlVtV/). Hence, in earlier experiments, Catalan-Spanish bilingual, unlike monolingual, infants were not surprised (and did not increase their looking time) when stimuli with similar but different vowels were presented at the test phase.

The development in the phonetic capabilities of Spanish-Catalan bilingual infants has been described as a temporary failure to discriminate native contrasts (Burns et al., 2007; Fennell, Byers-Heinlein, & Werker, 2007). However, the use of a measure based on the recovery of attention may have underestimated their real perceptual capacities and if tested under appropriate circumstances, the infants might in fact be able to discriminate these contrasts. The familiarization-preference procedure used in these earlier studies acts as an indirect measure of discrimination, for in this task there is no contingency between the infant's response and the change in the auditory stimuli. Rather it relies upon the surprise caused by experiencing an unexpected/new stimuli. Thus, features specific to the task may have contributed to the pattern of results observed with Catalan-Spanish bilingual infants. Indeed, a number of studies have suggested that the experimental task can hinder an infant's performance. For instance, Werker et al. (2002) observed that 14-month-olds, though not 17-month-olds, failed to react in a word learning switch task to a consonant contrast ([bih]-[dih]), the very same contrast they were able to perceive in a phonetic discrimination task. And yet, when infants were tested with a visual choice method instead of the switch task, 14-month-olds were successful with very similar contrasts ([bin]-[din]) (Yoshida et al., 2009). Similar studies conducted with bilingual infants have reported that 17-month-old bilinguals, though not monolingual infants at the same age, failed to respond to stimuli involving the [bih]-[dih] contrast when tested with the standard switch paradigm (Fennell et al., 2007). Recently, Mattock, Polka, Rvachew and Krehm (2010) have reported that 17-month-old bilinguals will actually outperform monolinguals in certain experimental conditions.

The present study is aimed primarily at testing the hypothesis that the vowel perception abilities of Spanish-Catalan bilingual infants match those of their monolingual peers. To this end, we adapted the anticipatory eye movement (AEM) procedure (McMurray & Aslin, 2004), a task in which the infant responds contingently to each change in the speech stimuli. It takes advantage of infants' ability to anticipate the appearance of a visual cueing stimulus following a regular trajectory after disappearing behind an occluder. After several presentations, infants learn to anticipate the expected location where the cueing stimulus is to reappear. The side of the occluder from which the cueing stimulus reappears is predicted by the auditory stimulus that is presented concurrently. In the original study, McMurray and Aslin (2004) explored speech categorization by investigating if infants could normalize for variations in duration and pitch in words. We modified this procedure to obtain a phonetic discrimination procedure. Accordingly, we removed the difference between the training and the test phase (used to measure generalization), making the visual reinforcer reemerge from the occluder in both phases. We compared infants' behavior at different moments during the experiment. We expected infants' behavior to be totally random at the beginning of the experiment but, if they were able to discriminate the vowel contrasts, to show correct anticipatory looks by the end of the session.

2.2.2. General Method

Stimuli. The stimuli were the same disyllabic CVCV nonsense-words [dɛði], [deði] and [duði] used in previous studies (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009). In each experiment, the stimuli consisted of 24 natural exemplars uttered by eight female speakers and produced in an Infant-directed Speech style. Infant-directed Speech has a higher pitch, extended intonation contours, and exaggerated phonetic cues, and is commonly preferred by infants from the first month of age (Cooper & Aslin, 1990).

Procedure and apparatus. Infants were exposed to 46 trials following an adaptation of McMurray and Aslin's procedure (2004). It comprises a two-alternative forced-choice (2AFC) paradigm that allows for the collection of many repeated measures for each infant and yields a response for each single stimulus. Each trial began with a visual cueing stimulus expanding and contracting (a cartoon of Sesame Street's Elmo) located below a blue T-shaped occluder3. The Elmo cartoon was 16 cm wide and 20 cm high and the T-Shaped occluder was 60 cm wide and 42 cm high. As soon as the infant focused her attention on the visual cue, the experimenter started the trial by pressing a key. Then the cartoon moved behind the T-shaped occluder at a constant velocity while the auditory stimulus (that corresponded to one of the two vowel categories) was played three times from the moment the visual cueing stimulus began to move. The visual cueing

[3] Unlike McMurray and Aslin (2004) we did not used an inverted T-shaped occluder. In this way we maximize the distance between the two spatial locations where the visual cueing stimulus could reappear and, hence, facilitate the coding of the infants' looks.

stimulus was occluded for 2440 ms. Finally, the cartoon emerged from the occluder at either the top left or the top right, predicted by the auditory stimulus played. Once outside, the visual cueing stimulus moved in such a way as to attract the infant's attention. Every four trials, one of three visual animated displays was presented to reengage the infant ("refreshment trials"). In those trials the infant watched visual animated displays that comprised bouncing balls moving across the screen accompanied by a soft whistle sound. The experiment was controlled by custom software programmed using Microsoft C+ with Microsoft Direct X libraries (an example of the videos can be found at http://www.sap.upf.edu/).

Token variability was gradually introduced to facilitate the task (Table 2.1 describes the procedure). Eight presentation orders were generated by crossing the stimulus category and the reappearance of the reinforcer to the left or to the right of the visual display. Within each presentation order, stimuli were ordered semi-randomly with a maximum of three trials of the same vowel category in a row.

Table 1. Token variability in the experiments.

Trials	Tokens	Speakers
1-10	6	6
11-23	12 (6 old, 6 new)	8 (6 old, 2 new)
24-46	24 (12 old, 12 new)	8 (old)

During the experiment, the infant was seated on the lap of their caretaker, who was given Climax 14P headphones to listen to music through so as to avoid any interference with the infant's behavior.

Testing took place in a dimly lit, sound-attenuated, 178 by 150 cm, laboratory room, where the screen was 75 cm from the participants. Two stereo loudspeakers (Philips Multimedia Speaker System) hidden behind the screen played the stimuli at 65 ± 5 dB (A) SPL. The images were reproduced through a Mitsubishi XL8U projector and projected on a 99 by 86 cm screen. Infants were recorded with a Canon MV750i video camera mounted under the screen, while the experimenter ran the experiment from outside the room, following the infants' eye movement through a Panasonic BT-S1460Y TV monitor.

Video Coding. A trained coder scored the videotapes frame-by-frame (1 frame = 40 ms) by categorizing infants' eye movements into four spatial locations: left, right, center or away from the display (see Figure 1). Looks shorter than 80 ms were discarded (Kóvacs, 2008). Trials were coded from the offset of the visual reinforcer to its reappearance. The resulting time-window analysis was of 2440 ms on average (ranging from 2400 to 2480 ms). An additional coder re-scored 25% of the videos to assess inter-observer reliability. The Pearson correlation coefficient between coders was .89 for Experiment 1 and .88 for Experiment 2.

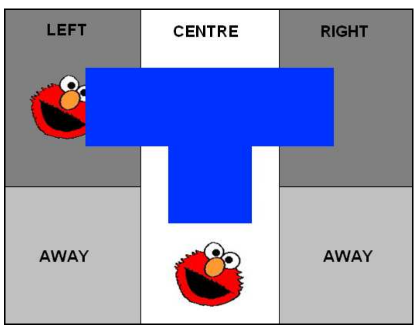

Figure 2.5. Visual stimulus, T-shaped occluder and coding areas.

Data Analysis. The 46 trials were divided into two blocks of 23 trials each. As in McMurray and Aslin (2004) a trial was scored as correctly-anticipated when the infant spent more time looking to the correct side (left or right) of the screen than to the incorrect one, and as incorrectly-anticipated when the infant spent more time looking to the wrong side (left or right). Looking times to center or away locations were not included in the analysis. Percentages of correctly- and incorrectly-anticipated trials were computed for each block.

2.2.3. Experiment 1: testing the procedure

This experiment was designed to test the functionality of the modified AEM paradigm to be used as a discrimination task. We tested a mixed group of monolingual and bilingual Catalan and Spanish infants in the discrimination of the /e/-/u/ contrast, with the same 24 disyllabic CVCV nonsense-words (12 [deði] and 12 [duði]) used in Sebastián-Gallés and Bosch (2009). This contrast is phonemic in both languages and distant in the vowel space. Previous research has demonstrated that all infants are able to discriminate for this specific contrast in a familiarization-preference procedure (Sebastián-Gallés & Bosch, 2009).

Participants. Eighteen infants from monolingual (n=9, 4 Catalan monolinguals and 5 Spanish monolinguals) and bilingual (n=9) environments between the ages of 7.15 and 8.15 months (M = 240 days; range = 233-255) were tested. All infants were full-term with no reported health problems. A detailed language questionnaire (Bosch & Sebastián-Gallés, 2001) was administered to establish the infants' language environment. For inclusion in the sample, infants were required to direct their gaze to at least one of the reinforcer's reappearance locations in a minimum of 9 trials per block. This inclusion criterion was implemented to ensure that the infant was engaged in the task. Nine additional infants were tested but excluded from the analysis due to fussiness (2), crying (1), side bias[4] (3) and not reaching the minimum 18-trial criterion (3). Participants were recruited by visiting new mothers at the Hospital Sant Joan de Déu and mothers-to-be at the Manso health clinic (Barcelona). Parental consent was acquired before running the experiment.

2.2.3.1. Results and Discussion

To assess discrimination, we submitted the proportion of *correctly-anticipated trials* to a repeated-measures analysis of variance (ANOVA) with block (First vs. Second) as the within-subjects factor and language group (Monolingual vs. Bilingual) as the between-subjects factor. Only a block effect was observed [$F(1, 16) = 6.27$, $p=0.023$]. T-test comparisons of means against chance (0.5) revealed significant differences in the second, [$t(17) =2.98$; $p=0.008$)], but not in the first block ([$t(17) =-1.27$, $p=0.221$]), demonstrating that infants had learned to anticipate the reappearance of the reinforcer in the second block of trials (see figure 2). As expected bilingual and monolingual infants performed equally, replicating previous findings (Sebastián-Gallés & Bosch, 2009).

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[4] Infants who directed more than 75% of their gazes throughout the experiment to one of the sides of the screen while the reinforcer was hidden were excluded from the final sample. This criterion of exclusion was not adopted in McMurray and Aslin's (2004) original procedure.

The results of this experiment showed that our modifications to the AEM procedure were useful for studying phonetic discrimination in 8-month-old infants.

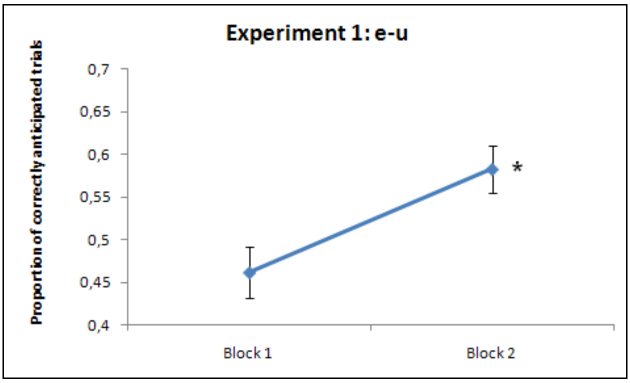

Figure 2.6. Proportion of correctly anticipated trials in blocks 1 and 2. Only results of block 2 were significantly different from chance. Bars indicate standard error.

2.2.4. Experiment 2: testing the /e/-/ ɛ/ contrast

This experiment tested the hypothesis that previous failures in vowel discrimination by 8-month-old bilingual infants did not reflect their actual phonetic sensitivities. The stimuli were the same 24 disyllabic CVCV nonsense-words (12 [deði] and 12 [dɛði]) used in previous studies to test the discrimination of the Catalan /ɛ/-/e/ contrast (Bosch & Sebastián-Gallés, 2003a). If bilingual infants are able to perceive the difference between /e/ and /ɛ/, they should be able to learn to anticipate the appearance of the cartoon in the same way as Catalan monolingual infants. By contrast, Spanish monolingual infants should not show any anticipatory responses either at the outset or at the end of the experiment.

Participants. Participants consisted of 54 infants ranging from 7.5 to 8.5 months of age divided in three groups according to their linguistic environment, using the same questionnaire as in Experiment 1. The 54 infants consisted of 18 Catalan monolinguals (CM) (M = 240 days; range = 228-250), 18 Spanish monolinguals (SM) (M = 239 days; range = 228-247) and 18 Catalan-Spanish bilinguals (B) (M = 236 days; range = 225-255). All the infants were full-term with no reported health problems. Thirty-six additional infants (10 CM, 17 SM and 9 B) were tested but excluded from analysis due to the following reasons: fussiness (7, 3SM, 2CM, 2B), crying (3, 2SM, 1B), side bias (7, 2SM, 3CM, 2B), not reaching the minimum of 18 trials criterion (16, 8SM, 4CM, 4B), parental interference (2) and equipment failure (1). The infants were recruited from the same pool as in experiment 1.

2.2.4.1. Results and discussion

As in the previous experiment the proportion of *correctly-anticipated trials* was submitted to a repeated-measures ANOVA with block (First vs. Second) as the within-subjects factor and language group (CM, SM, B) as the between-subjects factor. There was a main effect of block ($F(1, 51) = 16.546$, $p<0.001$), and a marginal interaction was reported between group and block ($F(2, 51) = 2.943$, $p=0.062$). T-test comparisons of means against chance (0.5) revealed that both Catalan monolinguals and bilinguals were only able to anticipate the reappearance in the second block ($t\ (17) = 3.027$; $t\ (17) = 3.287$, both $p < .009$), while Spanish monolinguals presented the same behavior in both blocks (second block $t\ (17) = 1.426$; $p=0.172$). These results are recorded in table 2 and figure 3.

These results indicate that bilinguals, in common with their Catalan monolingual peers, but unlike their Spanish monolinguals, can use the perceived difference between the /e-ɛ/ vowels to learn to anticipate the reappearance of the visual stimulus.

Table 2. Mean and Standard Deviations of the amount of correctly-anticipated and incorrectly-anticipated trials in each block in experiments 1 and 2.

		First Block		Second Block	
		Proportion of correctly anticipated trials	*T-test against chance (0.5)*	*Proportion of correctly anticipated trials*	*T-test against chance (0.5)*
Experiment 1 (/e-u/)		0.46 (0.13)	p=0.221	0.58 (0.13)	p=0.008
Experiment2 (/ɛ-e/)	Catalan monolinguals	0.49 (0.10)	p=0.577	0.59 (0.12)	p=0.004
	Spanish monolinguals	0.52 (0.14)	p=0.632	0.53 (0.09)	p=0.172
	Bilinguals	0.48 (0.12)	p=0.481	0.61 (0.15)	p=0.008

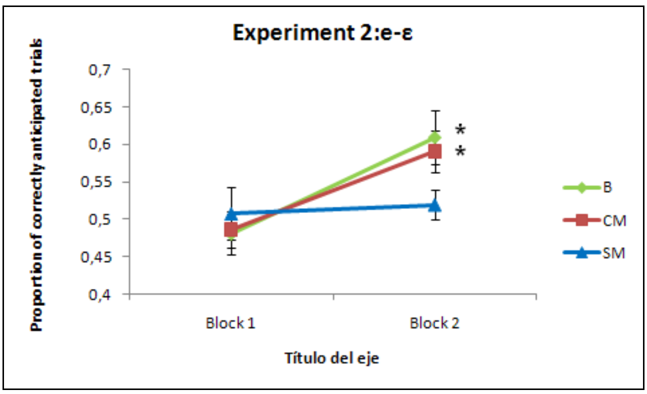

Figure 2.7. Proportion of correctly anticipated trials in blocks 1 and 2 for the three language groups (SM= Spanish monolinguals; CM= Catalan monolinguals; B= bilinguals). Results were significantly above chance in the second block for Bilingual and Catalan-monolingual infants. Bars indicate standard error.

2.2.5. General discussion

The goal of this research was twofold. First, it sought to assess the efficacy of an adaptation of the AEM procedure in order to test phonetic discrimination in infants. The results from the two experiments conducted above reveal that it is a suitable procedure for use with eight-month-old infants, even in perceptually challenging situations.

The second, and main goal, was to explore the perceptual abilities of Catalan-Spanish bilingual infants. Our results clearly show that Catalan-Spanish infants match their monolingual peers when tested using the anticipatory eye movement task. Both groups (but not that of the Spanish monolinguals) were able to anticipate where the visual cueing stimulus would appear, which was only possible if infants managed to perceive the differences between the vowels being tested. Significantly this demonstrates that previous studies have tended to misinterpret null results. The conjunction of the nature of the Catalan-Spanish input and the characteristics of the familiarization-preference procedure masked the real discrimination capacities of bilinguals.

The results reported here, however, raise new questions as to why Spanish-Catalan bilingual infants presented a different pattern of results to those of their French-English bilingual peers. As discussed above, it would seem that the number of cognates is a key factor in accounting for the different patterns of phonetic discrimination in these two bilingual groups. Yet, it should be borne in mind that both sets of experiments also vary in the type of phonetic contrasts studied

- vowels[5] in the case of Catalan-Spanish bilinguals and consonants in French-English bilingual infants. Indeed, a large body of literature indicates that vowel variability is less relevant than consonant variability in word identification tasks (Nazzi, Floccia, Moquet, & Butler, 2009; Toro et al., 2008). Although this does not explain our current results per se (particularly as monolingual infants should also present certain difficulties in perceiving some vowel contrasts), it may have favored the bias of Spanish-Catalan bilingual infants to partially neglect vowel changes in a familiarization-preference procedure[6].

The explanation we have put forward was motivated by the paradoxical developmental path taken by the phonetic discrimination capacities of Spanish-Catalan bilingual infants. However, our theoretical framework makes other predictions (some of which have already received empirical support). A first prediction refers to the fact that even adult bilinguals may be less responsive to slight vowel mispronunciations. Indeed, this was observed in (Sebastián-Gallés et al., 2005), where adult Spanish-Catalan simultaneous bilinguals were less sensitive to mispronunciations involving the /e-ɛ/ contrast than

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[5] Catalan-Spanish bilingual infants have been tested with only one consonant contrast: the fricative /s-z/ contrast. Several studies indicate that the discrimination of the /s-z/ contrast is not always easily observed in infants (Bosch & Sebastián-Gallés, 2003b; Best, 1994). Spanish and Catalan also differ in their inventory of fricatives: only /f/ and /s/ are common, while /ʃ/, /z/, /ʒ/ exist only in Catalan and /x/ and /θ/ only in Spanish. Thus, there is also considerable variability in the mapping of the two languages at the level of fricatives. This lack of correspondence may have induced a perceptual bias. The perception of fricative contrasts in bilingual populations is currently under study in our laboratory.

[6] Additionally, Sabourin and colleagues have observed that monolingual infants fail to respond to some vowel contrasts, especially in perceptually challenging situations (Sabourin & Werker, 2003).

early and highly skilled Catalan-Spanish bilinguals (individuals that had only been exposed to Catalan in the first years of life but who learnt Spanish very early in life and are highly skilled in this language). A further prediction refers to the specificity of this loss of responsiveness to some mispronunciations in word-learning infants. As mentioned, we assume that the existence of a high number of cognates accounts for the lack of response in the familiarization-preference procedure in Catalan-Spanish bilingual infants. If bilingual infants focus their word-learning mechanisms on the extraction of common phonetic structures, it will be cognates rather than non-cognates that will show less sensitivity to slight mispronunciations. At present, there is evidence to indicate that Spanish-Catalan bilingual infants and children accept mispronunciations of cognates as correct (Ramon-Casas, Swingley, Sebastián-Gallés, & Bosch, 2009), but do not do so for non-cognates (Ramón-Casas, 2009; although, note, that evidence for non-cognate words was obtained by testing older children).

Finally, the proposal we make implies a highly adaptive system where infants specifically tune their processing and representational capacities to better process the input: Catalan-Spanish bilingual infants give less weight to vowel variation than they do to consonant variation. There is considerable evidence pointing to the fact that infants between 8 and 12 months of age are highly sensitive to the distributional properties of the input (Maye et al., 2002; Maye, Weiss, & Aslin, 2008; Sebastian-Galles & Bosch, 2002), so it is not surprising that at this age bilingual infants show an adaptive strategy that is highly sensitive to the characteristics of the input. We should stress that the way we have framed the current explanation does not draw a solid line between the way the phonological and lexical systems are built in multidialectal and bilingual environments. In the case of the interrelationship between phonetic category building and the lexicon, infants raised in multidialectal environments represent the more radical case as for them almost all words are "cognates". Thus, the study of different bilingual populations should contribute to our general understanding of early speech development. To conclude, the explanation we have proposed awaits confirmation, but it does not compromise the basic conclusion of this study that bilingual infants do not experience any temporary failure in their phonetic perception capacities.

3. GENERAL DISCUSSION

The goal of the present dissertation was to address the interplay between initial sensory biases and language experience in speech perception during the first year of life. This work focuses on vowel perception during a period when vowel categories are reorganized in the infant. This dynamic interplay has been observed in two ways: On the one hand through the phenomenon of asymmetries in vowel perception (in section 2.1) and, on the other hand, through the role of task-demands on infants' performance (in section 2.2). Below I summarize the main results of the experimental studies and in the remaining sections I discuss the interpretation of the findings.

3.1. Summary of the findings

3.1.1. Asymmetrical relationships between native vowels

The first study, presented in section 2.1, explored the time-course of the influence of acoustic biases and distributional cues in infants' vowel perceptual asymmetries. The acoustic bias was examined based on infants' preference for peripheral vowels (Polka & Bohn, 2003). Distributional cues were investigated by comparing performance of infants from Catalan and Spanish monolingual environments, two languages differing in the frequency distribution of peripheral and medial vowels. While acoustic biases may be present from early in life, the effects of language-experience might not be behaviorally observable until phonetic categories are fine-tuned. Hence, infants were tested at three different developmental stages: before (4-month-olds), during (6-month-olds) and after (12-month-olds) perceptual vowel reorganization has presumably taken place.

Asymmetries were present in vowel perception, revealing what dimension (acoustic salience or frequency of occurrence) was considered relevant at each age tested. The privileged status of peripheral vowels (for the vowels included in the study) was confirmed in infants from both linguistic environments at the youngest ages (before and during perceptual reorganization), thus supporting the early effects of acoustic salience. In particular, infants at 4 and 6 months of age preferentially responded to the peripheral vowel /i/ regardless of their language background. However, infants' preferences shifted by 12 months of age, revealing a language-specific behavior: At this age infants preferred the more frequent vowel in their respective language. We expected older infants to show no asymmetries, given that the vowels tested were phonetic categories present in both Catalan and Spanish. Instead, despite both vowels shared the same linguistic status, infants showed a clear asymmetry favoring the more frequent vowel.

3.1.2 Bilingual vowel acquisition

The second study presented in section 2.2 addressed bilingual vowel acquisition and the contrasting results obtained previously with Catalan-Spanish and English-French bilinguals. In particular, Catalan-Spanish bilinguals were unable to discriminate a native vowel contrast at 8 months of age, whereas English-French bilinguals have shown the same discrimination abilities as monolingual infants. We hypothesized that the lack of discrimination of a native contrast in 8-month-old Catalan-Spanish bilinguals (previously observed in Bosch & Sebastián-Gallés, 2003a and Sebastián-Gallés & Bosch, 2009) was a consequence of task-demands of the familiarization-preference procedure coupled with the properties of the Catalan-Spanish bilingual input. In particular, we suspected that the non-contingency between the presentation of stimuli and infants' responses of the familiarization-preference procedures may have caused the lack of discrimination. Also we think that the number of cognates in the Catalan-Spanish input, as compared to the characteristics of the French-English input, could underlie the difference in results, because the high proportion of cognates between Catalan and Spanish may lead bilingual infants to ignore vowel changes. For this purpose the discrimination of bilinguals and Catalan and Spanish monolinguals was tested with an adaptation of an AEM paradigm (McMurray & Aslin, 2004), which does not rely upon novelty preferences. First, to validate the task, bilingual and monolingual infants were tested on a vowel contrast common for Catalan and Spanish and for which they have already shown discrimination with a familiarization-preference procedure (Sebastián-Gallés & Bosch, 2009). A brief description of the pilot studies carried out before designing the definitive procedure is provided in Appendix A. Furthermore, the task was also examined using adult participants (the results can be seen in Appendix B). Thus, once the efficacy of the AEM procedure was confirmed, infants were tested on a Catalan vowel contrast that 8-month-old bilingual infants failed to discriminate in previous studies using the familiarization-preference task (Bosch & Sebastián-Gallés, 2003a). In contrast with these previous results, when tested with the AEM procedure in the present study, bilingual infants showed evidence of discriminating the vowel contrast at the same age as their monolingual peers. These results then suggest that the familiarization-preference task used in prior studies may underestimate bilinguals' perceptual abilities. However, the fact that monolinguals were surprised by novel stimuli, but bilinguals were not, would suggest that the Catalan-Spanish bilingual input was leading infants to disregard some vowel changes. We propose that the high ratio of cognates between the two languages, which maintain consonant frames but vary vowels, might explain bilinguals' tolerance to vowel substitutions in familiarization-preference tasks.

3.2 Salience is modulated by distribution

Evidence suggesting that language experience can influence vowels salience in perception is provided in both of the studies presented in this dissertation. In the first study (section 2.1) we reported that for 12-month-olds' the most salient vowel was the more frequent of the contrast, a pattern clearly different from what is found at 4- and 6-month-olds. Indeed, at 4 and 6 months of age infants preferred the more acoustically salient vowel. This claim is corroborated by Spanish-learning infants' asymmetries, which shifted from an acoustically salient vowel (but not frequent) to a frequent vowel (although acoustically non-salient), following perceptual reorganization. Additionally, in the second study (section 2.2), we interpreted that the presence of a large number of cognates in the Catalan-Spanish bilingual input might lead infants to pay less attention to vowel variation. This would account for the lack of discrimination of certain native vowel contrasts in 8-month-old Catalan-Spanish bilinguals tested with familiarization-preference procedures. However, it is important to consider that when the tested contrast is distant in the acoustic space (and therefore acoustically salient) bilingual infants showed discrimination even in a familiarization-preference procedure (Sebastián-Gallés & Bosch, 2009). Overall, these results support the relevance of input properties of the input on the modulation of stimulus salience during perception.

The relevance of distributional information in the attunement of vowel perception is in consonance with current views on native phonetic acquisition. The developmental framework for Processing Rich Information from Multidimensional Interactive Representations (PRIMIR), proposed by Werker and Curtin (2005), maintains that statistical-learning mechanisms detect regularities in the signal that modulate the raw salience of properties in the input. Furthermore, it is argued that initial biases, the developmental level of the infant, and task-demands act as filters that configure the representation available to the infant in each moment. From another point of view, the Native Language Magnet Theory expanded (NLM-e) (Kuhl et al., 2008) also proposes that language-experience modifies phonemes' initial salience. Infants' sensitivity to the distributional patterns in the input warps perceptual space, where the instance that most often occurs functions as a prototype. Prototypes are more salient and act as perceptual magnets, such that the other members of the category are perceived as more similar to the prototype than the reverse. Our results have gone one step further and revealed that frequency of occurrence not only influences within-category structure, but also the relation between categories. Like category prototypes, the more frequent category was perceived as more salient than the less frequent category.

3.3 Task-demand relevance

The importance of task-demands in determining infants' discrimination behavior was highlighted in this dissertation. In order to achieve a clear understanding of the development of speech perception and propose adequate models, it is critical to tell apart the limitations on infant behavior imposed by the paradigm from those arising from their actual discrimination abilities. A clear instance of the important role of task demands is provided by the comparison of procedures based on novelty preferences versus those based in gaze anticipation, which can be drawn from the results provided in sections 2.1 and 2.2. Familiarization-preference and visual habituation paradigms assume that infants tend to look longer to novel (non-habituated) than to habituated stimuli, a type of behavior that is taken as an index of discrimination. However, it is important to note that infants only show novelty preferences if they perceive the difference to be salient. This fact can be evidenced in the discrimination patterns observed in the study of asymmetries in vowel perception (section 2.1). Although infants discriminated the vowel contrast /e/-/i/ at the three ages tested (4-, 6- and 12-month-olds), directional asymmetries emerged, to the extent that the discrimination was only significant in one direction of change but not in the other. Hence, if infants had been tested only being habituated to the salient and tested with the non-salient stimuli, the null results would lead (wrongly) to the claim that infants do not discriminate /e/ from /i/. However, discrimination in the other direction of change (from the least to the most salient stimuli) proves that infants have the ability to discriminate the contrast, and therefore that in fact, the task measures the salience of the difference between novel and familiar stimuli.

Thus, the present results draw attention to the danger of misinterpreting null results as a lack of discrimination, as exemplified in bilinguals' vowel perception (section 2.2). When tested with the familiarization-preference procedure, 8-month-old Catalan-Spanish bilinguals did not show novelty preferences for the Catalan /e-ɛ/contrast (Bosch & Sebastián-Gallés, 2003a). This contrast is non-salient, and therefore difficult to discriminate: on one hand, the vowels are close in the acoustic space, and on the other hand, the vowel /ɛ/ is not frequent in the input bilinguals are exposed to. However, the lack of discrimination cannot be explained by the low salience of the contrast nor by task-demands only, as if this were the case Catalan monolinguals would also have had difficulties in this discrimination. According to this argument, we have proposed that the Catalan-Spanish bilingual input might reduce the salience of vowel changes. This would be especially evident when testing infants with acoustically weak contrasts, but not if the contrast is acoustically salient. Nevertheless, bilinguals' tolerance (lack of responsiveness) to vowel changes does not imply that they are unable to discriminate the contrast. In fact, the use of the AEM procedure revealed that when bilingual could access the difference between /e/ and /ɛ/, being more sensitive to real discrimination abilities than procedures based on novelty preferences.

As mentioned in the introduction, the contradictory results obtained when varying task-demands are well accounted for by the PRIMIR framework (Werker & Curtin, 2005). Indeed, PRIMIR's motivation was to integrate infants' apparently divergent results in different behavioral tasks. This framework proposes that task-demands, jointly with the developmental level of the infant and initial biases, determine the representation available to the infant. Thus, same developmental level infants will show availability of a specific representation depending on task-demands. PRIMIR explains the different level of access to phonetic detail that has been observed when using the familiarization-preference and AEM procedures.

3.4 Concluding remarks and open questions

1. Acoustic salience and distributional cues affect vowel asymmetries. The results of the first study (section 2.1) indicate that the timing at which salience and frequency distribution have an influence on perception differ along the first year of life. Acoustic salience affects infants' preferences before and during perceptual reorganization, while frequency effects are not behaviorally observable until infants are well beyond the attunement of native vowel categories. However, the time-course of these effects needs to be investigated further, as there are some issues to be answered before completing the picture.

First, it remains as an open question whether the preference for peripheral vowels is a byproduct of language exposure or whether it is an innate bias, as Polka and Bohn (2003) have noted previously. This first possibility is based on the evidence that in infant-directed speech (ID) vowel realizations tend to use exaggerated phonetic features, such that peripheral vowels /i/, /u/ and /a/ occupy a larger vowel space. This is the case across the several languages tested, like American-English, Australian-English, Japanese, Russian and Swedish (Andruski, 1999; Kuhl et al., 1997).

Second, it has been shown that the privileged status of peripheral vowels influence adult vowel perception. In an ERP study testing Catalan-Spanish bilingual adults, Vera-Constán (2010) found larger amplitude and shorter latency MMN responses when the middle vowel /e/ acted as the standard stimulus and the peripheral vowel /i/ was the deviant than in the reverse situation. Additionally, Polka, Molnar, Ménard, Baum and Steinhauer (2009) found language-universal asymmetries in the MMN response in English, French and bilingual adults favoring peripheral vowels. However, the results reported in the present dissertation do not reveal whether acoustic biases are in fact present in 12-month-old infants. The question is whether frequency effects arise because distributional cues prevail over acoustic biases that are nevertheless present, or else because the acoustic bias is no longer present. This question could be answered testing asymmetries with a vowel contrast made up of vowels equally frequent but differing in acoustic salience, like the Spanish /a/-/e/ contrast, where /a/ is more salient (because of being peripheral) but very similar in frequency to /e/ (frequency of occurrence in Spanish: 29%/a/ and 27%/e/, Alcina & Blecua, 1975). If the bias for peripheral vowels is still operational at 12 months of age, asymmetries should favor the vowel /a/. Nevertheless, it could be the case that despite the presence of acoustic biases, these might not be strong enough to affect asymmetries in a behavioral task, but still be observable with more sensitive measures.

Finally, the results of the present dissertation rise the question of why asymmetries are present for some contrasts but not for others. Narayan et al. (in press) tested the discrimination of a contrast made up with consonants differing in salience (the distinction /n/-/ŋ/, where /ŋ/ is the least salient consonant), but found no asymmetries neither at 6-8 months of age (when Filipino-learning infants did not give evidence of discrimination of the native contrast) nor at 10-12 months (when infants discriminated the contrast). As it has been already noted, this divergence in the results cannot be explained by differences between vowels and consonants, as asymmetries have also been found using consonantal stimuli (Kuhl, Stevens, Hayashi, Deguchi, Kiritani, & Iverson, 2006a). It might be that other acoustic characteristics of the /n/-/ŋ/ contrast influence infants' behavior to not show asymmetries despite the difference in salience.

2. *Vowel discrimination in bilinguals is comparable to that in monolinguals'*, as infants' performance on the AEM task revealed. Nevertheless, bilinguals' lack of discrimination behavior in the familiarization-preference procedure used in earlier studies needs to be explained. We have attempted such an explanation, based on a combination of the nature of the Catalan-Spanish input and the characteristics of the task, whose join effect masked bilinguals' real discrimination capacities. However, the proposal that bilingual infants give less weight to vowel than to consonant variation because the input contains plenty of

cognates needs to be further examined. This claim could be corroborated with infants growing up in multidialectal contexts. These infants constitute a more radical case than bilinguals, as almost all of the words are "cognates" (given that in dialectal variation vowel differences play a key role). These infants would also ignore vowel variation when tested with habituation procedures. However, it has to be noted that the lack of novelty preferences for vowel changes is not expected in all the cases, as bilingual infants succeeded in the discrimination when the contrast tested was distant in the acoustic space. Thus, the prediction is that infants raised in multidialectal environments would tolerate vowel changes especially for those vowel contrasts close in the acoustic space.

Additionally, if the speculation that the high number of cognates in the bilingual input leads infants to ignore vowel variation turn out to be right, then it would be interesting to explore whether this tendency is transferred to other domains. For instance, it has been argued that vowels and consonants have a different role in infants' language acquisition, such that consonants carry lexical information and vowels syntactic cues (Nespor et al., 2003). In accord to this idea, it has been found that adults rely more strongly on distributional regularities amongst consonants to extract words in a continuous artificial speech stream (Bonatti et al., 2005), but they rely more strongly on regularities amongst vowels in order to generalize structures (Toro et al., 2008). Furthermore, Pons and Toro (under review) have found that 11-month-olds monolingual infants could extract rules from vowels but not from consonants. In this context, bilinguals' tolerance to vowel variation might hamper their ability to extract regularities from vowel structures. Nevertheless, bilingual infants have learnt to not pay attention to vowel variation because vowels do not differentiate lexical items. Hence, it might be argued that bilinguals' tolerance to vowel changes would be restricted to lexically related tasks, and therefore would not affect rule extraction. This is an empirical question that could help to answer to which extent the properties of the input shape infants' processing.

4. APPENDIX A: Description of the procedures of the AEM Pilot studies

Four pilot studies were carried out before designing the definitive AEM procedure implemented in section 2.2.2.

4.1. First pilot study

Four differences are found between the first pilot study respect to the procedure used in the final version. (1) Infants could be presented with an unlimited number of trials and the experimenter finished the experiment when the infant was visible bored/tired. (2) Trials were presented in a totally random sequence. (3) There were 6 different possible Sesame Street cartoons acting as visual cueing stimulus. (4) The visual reinforcer (the cartoon) disappeared just after it reemerged from the occluder.

Eight infants were tested with this procedure, and showed no motivation to look for the visual cueing stimuli.

4.2. Second pilot study

To motivate infants to search for the reappearance of the visual cue, movement was added to the visual stimulus once it reemerged from the occluder. The visual cues could move in three different ways: expanding, circling and moving up and down.

The results of 9 additional infants showed that despite the modification increased infants' interest in the task, they were not able to anticipate the reemergence of the reinforcer. The hypothesis was that the random presentation of the trials may have confused infants. Occasionally, at the beginning of the experiment, infants were exposed to more than 5 trials in a row with the visual reinforce emerged on the same location. Thus, infants showed a large bias to anticipate their gaze to that specific side of the screen, therefore preventing infants from realizing that the location of reappearance of the visual reinforcer was predicted by the auditory stimuli played concurrently.

4.3 Third pilot study

Hence, in the third pilot study it was decided to present stimuli in a semi-random order (a maximum of three trials of the same vowel in a row), to avoid creating a bias in infants' behavior. Additionally we exposed infants to only 46 trials, as was the maximum number of trials that infants looked at before getting fussy in the second pilot experiment (when the number of trials of exposure was unlimited and the experimenter finished when the infant was bored). However, 10 infants tested did not show an anticipating behavior. The hypothesis was that the presentation of 6 different visual cueing stimuli was hindering learning. Infants might be searching for an association between a specific visual stimuli and one side of the screen, rather that realizing that it depended on the auditory stimuli presented.

4.4. Fourth pilot study

In the fourth pilot study we set up the definitive procedure. Only one visual cueing stimulus (a cartoon of Elmo from Sesame Street) was presented, which after reemerging from the occluder moved in an attractive way (as described above). Again, infants were exposed to 46 trials presented in a semi-random fashion. Finally, infants were engaged enough in the procedure, showing discrimination behavior.

5. APPENDIX B: Testing the AEM procedure with adults

This study was designed to further test the functionality of the Anticipatory Eye Movement (AEM) discrimination procedure in adult participants. As it is not possible to find Catalan monolingual adults (everybody who has Catalan as the native language is also exposed to Spanish or French, at least during the school years), we studied two groups of highly proficient bilinguals. One group of them was born in Spanish monolingual families (Spanish-Catalan bilinguals) and the other group had Catalan as the native language (Catalan-Spanish bilinguals). To resemble infants' experimental situation, and adult participants were asked to guess the location where visual reinforcer reappeared (which was predicted by the auditory stimulus presented concurrently, containing either vowel /e/ or /ɛ/) without information regarding the relevant dimension that categorized stimuli, contrary to traditional adult studies. Also, exactly the same stimuli as in the infant version were used, so to succeed in the task participants were required to normalize over 5 female speakers and over differences in length, syllable duration and pitch contour. Therefore, the main goal of this work was to test whether adults could solve the task (despite the added difficulty of the high variability of the stimuli). Additionally, the fact that feedback is available to participants (as the reappearance of the visual stimulus indicates the right answer in each trial), raised the possibility that even Spanish-Catalan bilinguals could learn to anticipate the visual reinforcer's reappearance location, despite having shown troubles in discriminating the /e-ɛ/ contrast in other studies (Pallier, Bosch, & Sebastián-Gallés, 1997).

We compared the performance of Spanish-Catalan and Catalan-Spanish bilinguals on a Catalan native vowel contrast /e/-/ɛ/ across three tasks: an adult-adaptation of the AEM discrimination task used with infants, a categorization task and a lexical decision task. Spanish-Catalan bilinguals (L1 Spanish and L2 Catalan) have been reported to show a different level of performance in the categorization and the lexical decision tasks, being the categorization task easier than the lexical decision, while Catalan-Spanish bilinguals performed optimally in both tasks (Sebastián-Gallés & Baus, 2005). We looked at participants' performance in the AEM task and compared its difficulty with the results in a Categorization and in a Lexical Decision tasks.

5.1. Method

Participants. 40 Spanish-Catalan (average age: 21) and 20 Catalan-Spanish (average age: 22) early bilinguals participated in the experiment. They were undergraduate students at the University of Barcelona. Participants were asked to fill out a questionnaire after the experiment. Spanish-Catalan bilinguals' responses to this questionnaire show that all of them had learned Spanish as L1 but acquired Catalan as their L2 at a mean age of 4.5 (SD = 2) and that they are currently using Catalan on a regular basis. They scored their L1 and L2 proficiency levels on four domains (speech comprehension, speech production, reading and writing), on a 4 point scale (4 = native speaker, 3 = good level; 2 = medium level; and 1 = poor level). The average of the participants' responses to the four domains was 4 for

L1, and 3.7 for L2. Catalan-Spanish highly-proficient bilinguals acquired Spanish as their L2 at a mean age of 4.7 (SD=2.1). They started using the L2 regularly from the age of 5.8 (SD=2.4), and they were currently using Spanish on a regular basis. The average of participants' proficiency on the four domains was of 4 and 3.8 in L1 and L2 respectively.

As there are important differences in the realization of the /e/-/ɛ/ vowel contrast across different Catalan dialects, only bilinguals from the Barcelona Metropolitan Area were included in the study. Also, because some dialects of the eastern provinces of Andalusia produce the /e-ɛ/ contrast, individuals having at least one of their parents coming from these provinces were not included in the sample.

Stimuli, Procedure and Analyses. For the AEM task, the stimuli were the same as in section 2.2.2. The AEM task was adapted to test adult participants. In infant's task the ability to anticipate the appearance of a visual cueing stimulus following a regular trajectory after disappearing behind an occluder was assessed, with the side of the occluder from which the cueing stimulus reappears is predicted by the auditory stimulus that is presented concurrently ([dɛði], tokens predict reappearance on one side and [deði] tokens on the other). After several presentations, if infants are able to discriminate the auditory stimuli, they learn to anticipate the expected location where the cueing stimulus is to reappear. Thus, infants' behavior is expected to be at random at the beginning of the experiment but to show correct anticipatory looks by the end of the session. In the adult version of the task, the presentation of the visual and auditory stimuli and the number of trials were exactly the same than in the infant version. What changed was the response obtained from the participant. Instead of tracking subjects' anticipatory looks, they were asked to press a key to predict the reappearance of the visual stimulus on the right (pressing the right arrow in the keyboard, →) or on the left of the occluder (the left arrow, ←). Subjects had to press the key before the visual stimulus reappeared from the occluder, otherwise their responses were not included in the analyses. They were not informed about what predicted the reappearance of the visual stimuli, to make the task as similar as possible to the one that infants faced. The 46 trials presented were divided into two blocks of 23 trials each. If participants discovered what guided the reinforcer reappearance, we expected better results in the second block. Percentages of correctly-anticipated trials were computed for each block.

For the Categorization and the Lexical Decision tasks, the same stimuli, procedure and analyses as in Sebastián-Gallés and Baus (2005) were used. In the Categorization task, subjects were presented with a continuum of 7 points ranging from /e/ (endpoint 1) to /ɛ/ (endpoint 7). Participants were asked to determine if the vowel presented was more like the first vowel in the word *Pere* ([perə] -Peter-) or in the word *pera* ([pɛrə] -pear-). The average percentage of /e/ categorizations to the endpoints of the continuum was computed for each subject (to stimuli 1 and 2 and to stimuli 6 and 7), and a categorization score was calculated subtracting the percentage of /e/ categorized in each endpoint. Scores close to 100 reflect that participants considered the stimuli close to the /e/ endpoint to be /e/-like and the stimuli close to the /ɛ/ endpoint not /e/-like. Scores

close to 0 mean that participants categorized stimuli in to the /e/ and /ɛ/ categories at random.
In the LDT participants had to decide if the auditory stimulus presented is a word or a non-word. Non words were created by replacing a vowel in a word. There were 3 types of words and non-words: Catalan words containing the vowel /ɛ/, like *galleda* [gəλɛðə] (bucket), from which a non-word was created changing the vowel /ɛ/ for the vowel /e/ (ɛ -stimuli); Catalan words containing the vowel /e/, like *finestra* [finestrə] (window), with their corresponding non-words where the vowel /e/ is replaced by vowel /ɛ/ (e-stimuli); and control words, which were Catalan words containing neither /e/ or /ɛ/, like *raspall* [rəspaλ] (brush), from which non-words were created changing the stressed vowel by another vowel than /e/ or /ɛ/ (and controlling than the resulting non-word is not a real word in Catalan).

Participants were warned that the difference between words and non-words lied in a vowel change, and that in most of the changes it will entail a replacement of the vowels /e/ and /ɛ/. To control the bias that Spanish-Catalan (Spanish as L1) showed to consider e-stimuli and e-stimuli non-words as real words, A' statistics were used as an index of participant's discrimination of words and non-words.

Following (Munro, Flege, & MacKay, 1996), to determine the pattern of native-like performance a cut-off point of minus 2 standard deviations from the mean of Catalan-dominant subjects was calculated. The amount of Spanish-dominant bilinguals below the native cut-off point is discussed for each task.

5.2. Results and discussion

5.2.1. AEM Discrimination Task

The average of correctly-anticipated trials of Spanish-Catalan bilinguals in the first and second blocks was of 63% (SD=0.18) and 72% (SD=0.16) respectively, while the average of Catalan-Spanish bilinguals was of 80% (SD=0.16) and 91% (SD=0.10) for each block. Participants' out-of-time responses (i.e. given after the visual reinforce began to re-emerge from the occluder) were not included in the analyses. Although Spanish-Catalan bilinguals' results were over chance, their performance was worse than the bilinguals with Catalan as L1. The cut-off point for the AEM task yielded a value of 46% for the first block and 69% for the second block. No Catalan-Spanish bilinguals scored below the cut-off points in the first or second blocks. In the first block, only 4 Spanish-Catalan bilinguals (10%) performed below the cut-off point, while in the second block 21 Spanish-dominant bilinguals (52%) performed below the cut-off point (see figure 5.1). These results indicate that as participants advance in the task, they get better in the ability to predict the reappearance of the visual stimulus. However, while in the first block the 90% of the Spanish-Catalan bilinguals behave as native-like, this value falls to a 48% in the second block. This difference reflects the learning of the Catalan-dominant bilinguals from the first to the second block and the challenge for Spanish-dominant bilinguals to improve in the task.

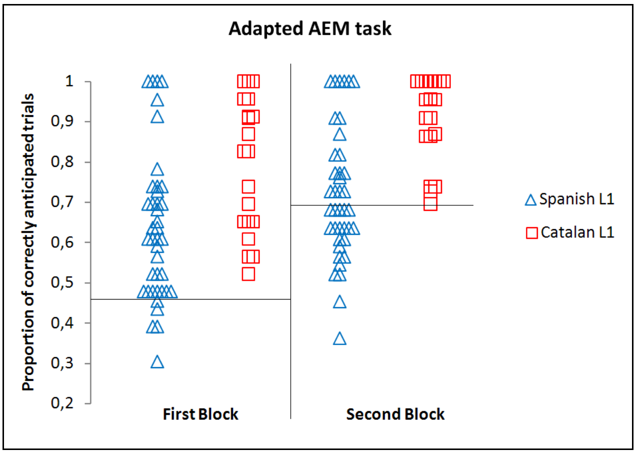

Figure 5.1. Individual proportion of correctly anticipated trials in blocks 1 and 2 for the two language- groups (Catalan-dominant and Spanish-dominant bilinguals). The horizontal bars show the cut-off point.

5.2.2. Categorical Perception Task

The average categorization score of Spanish-Catalan bilinguals was 72 (SD=30), and of Catalan-Spanish bilinguals was 96 (SD=4). These results show that Catalan-Spanish bilinguals categorized the /e/ and /ɛ/-like stimuli much better than Spanish-Catalan bilinguals, a group that shows a huge variability in their responses. The cut-off native-like point for this task was of 86. Only one Catalan-dominant subject scored below this value, while 18 Spanish-dominant participants (45%) scored below the cut-off point (see figure 6).

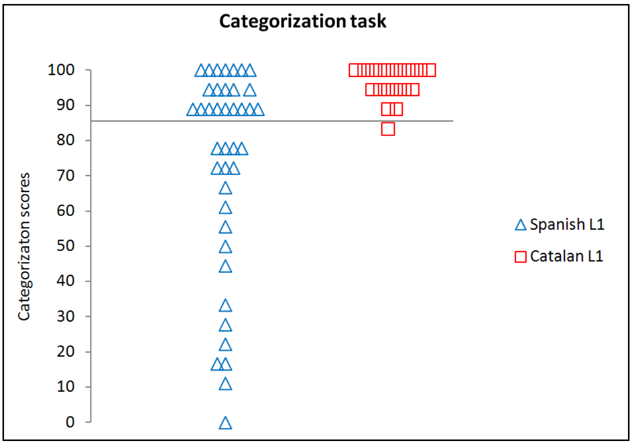

Figure 5.2. Individual categorization scores for each group of participants. The horizontal bar indicates the cut-off point.

5.2.3. Lexical Decision Task

The Spanish-dominant bilinguals' average A' scores for ɛ-stimuli and e-stimuli were 0.65 (SD=0.13) and 0.68 (SD=0.15) respectively, clearly worse than their performance on control stimuli, where they scored an average of 0.95 (SD=0.09). For Catalan-Spanish bilinguals, the A' scores were 0.90 (SD=0.09) for ɛ-stimuli, 0.92 (SD=0.08) for e-stimuli and 0.96 (SD=0.05) for control stimuli. The cut-off points established were 0.77 for e-stimuli and 0.72 for ɛ-stimuli. As a result, one Catalan-Spanish bilingual scored under these values (5%, the same person scored under the cut-off points for ɛ-stimuli and e-stimuli), while for Spanish-Catalan bilinguals, 26 scored under the cut-off point for e-stimuli (65%) and 27 below the cut-off point for ɛ-stimuli (67%). Individual scores are shown in figure 7.

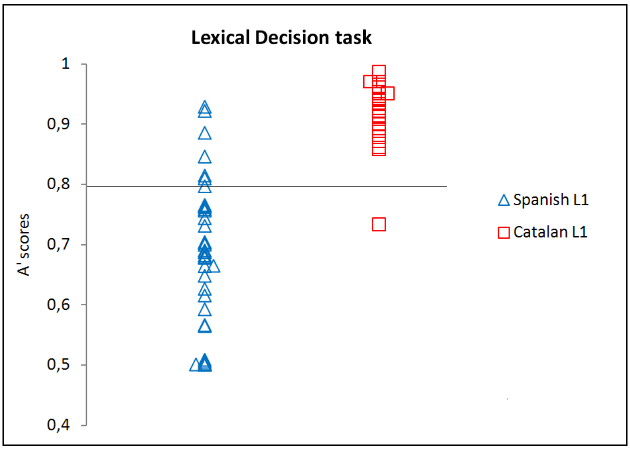

Figure 5.3. Individual A' scores, averaged between A scores to ɛ-stimuli and A' scores to e-stimuli.

In summary, this study replicates the results obtained in (Sebastián-Gallés & Baus, 2005) in the categorization and the lexical decision tasks. More interestingly, it shows that the adaptation of the AEM task can be used with adult subjects and that the performance of the participants in the second block is useful to tell a part Catalan-Spanish and Spanish-Catalan bilinguals. Nevertheless, in the light of the results, the AEM task was difficult for native participants, as Catalan-Spanish bilinguals were not performing at ceiling (in contrast to their results in the categorization task). In fact, it can be argued that the AEM task is even more difficult than the lexical decision task, as in the former participants had to struggle with stimuli highly variable and without any instructions about what dimension in the stimuli was relevant to solve the task.

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