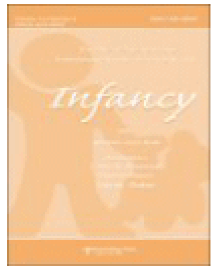

Phemic contrasts under construction? Evidence from Basque

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Phonemic contrasts under construction? Evidence from Basque

1. Introduction

During the first year of life, monolingual infants develop a heightened sensitivity to speech sounds that belong to their native phonemic repertoire. This development has been attributed to word learning, statistical and/or distributional learning, and acquired distinctiveness (Saffran, 2014; Werker, Yeung, & Yoshida, 2012). The perception of the English /l/-/r/ sound contrast is a well-known example of this developmental pattern. English-learning infants' performance improves between 6 and 12 months as a result of longer experience with native-language phonological properties (Kuhl et al., 2006). Similar developmental patterns have been reported for various speech contrasts (e.g., Polka & Werker, 1994; Werker & Tees, 1984). In this paper, we analyze the effect of Basque exposure on the perceptual change for two Basque consonant contrasts by infants listening to Spanish and Basque.

Traditionally, the developmental patterns have been accommodated within attunement theories of development. On this view, during the beginning of the first year, infants can discriminate both native and non-native similar-sounding speech sounds; toward the end of the year, infants enhance their ability to discriminate phonological categories that are present in their language environment (Aslin, Werker, & Morgan, 2002; Kuhl et al., 2006; Polka, Colantonio, & Sundara, 2001; Sundara et al., 2018; Werker & Tees, 1984, 1999). In parallel, if certain speech sounds are not phonemic in the infants' language, discrimination of these sounds declines toward the end of the first year (Anderson, Morgan, & White, 2003; Kuhl et al., 2006; Werker & Tees, 1984). Typically, the change due to language-specific experience occurs around 6 months of age for vowels and around 10 months for consonants.

However, Narayan, Werker, and Beddor (2010) have suggested that this pattern does not hold for all speech sounds. They reported that the *acoustic salience* of a contrast interacts with infants' ability to discriminate those sounds. English-learning infants could discriminate an acoustically robust native consonant pair (/m/-/n/) at both 6-8 and 10-12 months of age, but they could not discriminate an acoustically less salient Filipino contrast (syllable-initial /n/–/ŋ/) at any of the tested ages. Filipino-learning 6-8-month-olds also could not discriminate this difficult contrast that is in their native input, but this ability developed by 10-12 months of age. The older Filipino infants' success is presumably due to their native language exposure to the acoustically non-salient contrast.

Sundara et al. (2018), in contrast, reported that young English-learning infants are in fact able to discriminate the Filipino /n/–/ŋ/ contrast. Given Narayan et al.'s stimuli, English-learning 4- and 6-month-old infants were sensitive to the subtle phonetic differences that distinguish /n/ and /ŋ/; young English- and French-learning monolingual infants could discriminate additional subtle non-native contrasts. Even though both studies used a visual fixation paradigm in which infants' attention to an auditory stimulus is inferred based on the amount of time they look toward the source of the sounds, there was one major methodological difference between the two. Narayan et al. (2010) employed a non-infant-controlled version of the habituation task: Stimuli were presented for the same fixed amount of time for all infants regardless of whether the infant looked toward the screen. Sundara et al. (2018) instead used an infant-controlled version of the paradigm: when infants did not look toward the screen (the source of the auditory stimulus), the sounds were terminated. The infant-controlled version makes it easier for infants to learn the contingencies between looking and the auditory stimulus. Sundara and her colleagues argued that this methodological difference accounts for the different results.

Theories of speech perception development have primarily focused on monolingual language acquisition because most previous studies of speech perception development have tested monolingual infants (for a review, see Gervain & Mehler, 2010). The relatively small number of studies done with bilingual infants show that they discriminate phonemic contrasts in both of their two native languages (e.g., Albareda-Castellot, Pons, & Sebastian-Galles, 2011; Burns, Yoshida, Hill, & Werker, 2007; Sundara, Polka, & Molnar, 2008). For example, Sundara et al. (2008) tested French-English infants' discrimination of the (English) /d/–/ð/ contrast, using the infant-controlled visual habituation procedure. In this procedure, two talkers were used during the habituation phase and all test stimuli were presented by a new (third) talker. With this procedure, infants had to overlook within-category phonetic variation, and focus just on the category change across different voices. Sundara et al. found that bilinguals' /d/–/ð/ discrimination was comparable with that of their English monolingual peers. Between 6 and 8 months of age, all three language groups (monolingual English, monolingual French, bilingual English-French) succeeded in discriminating the contrast. By 10-12 months of age language-specific effects emerged, and French monolinguals did not show discrimination.

In the current study, we use the infant-controlled version of the habituation procedure, following Sundara et al. (2008; 2018). As in Sundara et al. (2008), we employ a multiple-talker procedure, in this case to measure the category discrimination capacity of Spanish-Basque bilinguals and monolinguals. We test the impact of acoustic salience and language-specific experience in speech perception development by assessing the discrimination of acoustically subtle Basque contrasts in infants with varying amounts of exposure to Basque. Previous studies indicate that the amount of exposure bilingual infants receive to one of their languages affects their perception abilities (e.g., Molnar, Lallier, & Carreiars, 2014). Specifically, we test infants' discrimination of two Basque sibilant contrasts previously studied in adults (Larraza, Samuel, & Oñederra, 2016; Samuel & Larraza, 2015). One is a fricative contrast between voiceless apical alveolar /s̺/ and laminal alveolar /s̻/. Both fricatives have the same passive place of articulation (i.e., alveolar). However, apical alveolar /s/ is pronounced with the tip of the tongue whereas laminal alveolar /s/ is made with the blade of the tongue. The second contrast is a place-of-articulation contrast between voiceless affricates: palatal /tʃ/ versus laminal alveolar /ts̻/. The perceptual salience of place-of-articulation seems to be lower than voicing or manner (Miller & Nicely, 1955). Even so, our previous studies showed that, regardless of whether Spanish or Basque was the listener's L1, bilingual adults' discrimination accuracy was similar for the Basque affricate and fricative contrasts.

Because our infants were growing up in a Spanish-Basque bilingual area, it is worth noting that these contrasts do not exist in Castilian Spanish; apical /s̺/ is the only sibilant fricative, and palatal /tʃ/ is the only affricate. Therefore, exposure to Basque should be necessary to develop the discrimination of these contrasts. Conversely, lack of exposure to Basque should decrease discrimination after 10 months of age. Spanish-learning infants will classify most realizations of fricative and affricate sibilants as /s̺/ and /tʃ/ because this is what they have in their language. In terms of distributional learning mechanisms, they are exposed to a unimodal distribution. In contrast, in Basque, the same acoustic space for fricative and affricate exemplars constitutes a bimodal distribution. This statistical distribution has been shown to be the basis for creating native phonological categories (e.g., Maye, Werker, & Gerken, 2002; Werker, Yeung, & Yoshida, 2012): Exposure to a unimodal distribution results in a single phoneme category (the case for Spanish-learning infants), whereas two categories develop from exposure to a bimodal distribution (the case for Basque-learning infants).

Given that these two sibilant contrasts are among the very few phonemic contrasts that differ between the current Spanish and Basque inventories, they provide an appropriate test to compare infants' capacity to accommodate phonetic variation in fricatives and affricates. We will refer to the critical sounds using their Basque orthography: The "S" grapheme corresponds to the apical fricative /s̺/ and "Z" is used for the laminal fricative /s̻/. For the affricates, "TX" represents the palatal /tʃ/ and "TZ" represents the laminal alveolar /ts̻/.

Acoustically, apical S and laminal Z differ in peak amplitude, spectral centroid and duration (Table 2 in Larraza et al., 2016). TX-TZ are distinguishable in terms of peak amplitude and spectral centroid, but not duration (Table A1 in Samuel & Larraza, 2015). Appendix A summarizes these measurements. In articulatory terms, the TX-TZ affricate contrast should be more salient than the S-Z fricative contrast, based on the place of articulation for each contrast. Both S and Z are pronounced with the tongue touching the alveolar ridge, whereas TX and TZ have more distinctive places of articulation; TX is palatal and TZ is laminal alveolar. We also considered whether the two sides of a contrast were equally frequent[1]. These acoustic and articulatory differences are apparently not extremely robust from a perceptual perspective. Highly proficient Basque-Spanish bilinguals who started learning Basque before age three have more difficulty discriminating these contrasts than other common contrasts shared by their two languages, but of course proficient Basque speakers do make the distinction. The two contrasts produce similar discrimination scores, around 93% correct, in adult listeners (Larraza et al., 2016; Samuel & Larraza, 2015).

While the results of Narayan et al. (2010) may be due in part to procedural details, their theoretical claim makes good sense: Subtle contrasts may follow a different developmental trajectory than is typically described in attunement theory. With this perspective in mind, in order to understand the role of language experience in the development of speech perception, specifically for acoustically subtle contrasts, we tested infants who received little exposure to Basque during their first year of life (Spanish-dominant infants) and infants who varied in their exposure to

[1] At the lexical level, the two sounds of each of the contrasts do not differ in their frequency of occurrence (for more details, see Samuel & Larraza, 2015 and Larraza et al., 2016). At the morphological level, there is a preference for Z and TZ, given the characteristics of Basque morphemes. However, regardless of frequency, these distinctions must be learned by any speaker of Basque.

Basque (Spanish-Basque bilingual and Basque-dominant infants). Due to natural variation, the population provides an ideal testbed because the mix of language exposure ranges between almost no Basque to virtually all Basque. This allows us to test whether the typical acquisition pattern holds for relatively subtle contrasts like the Basque fricatives and affricates.

Attunement theories rely on several variables to explain the process of language development: experience with the native language, perceptual distance of the sounds to be perceived, relative distributional frequency of occurrence of the phonemes of interest, etc. A natural prediction of this perspective is that discrimination of our acoustically subtle phonemic contrasts should be facilitated by increased exposure to Basque: Infants with more exposure to Basque should show increased sensitivity to the fricative and affricate Basque contrasts, while the sensitivity of infants with very little exposure to these contrasts should decrease. If the initial discrimination of acoustically subtle phonemic contrasts is possible without language-specific experience, as suggested by most attunement hypotheses, then all infants should discriminate the Basque fricative and affricate contrasts at 6-7 months of age, given our use of the sensitive infant-controlled visual fixation procedure (Sundara et al., 2008; 2018).

2. Methods

2.1. Participants

156 infants were tested, but we only included in the analysis those who finished both the fricative and affricate experiments; this allowed us to examine the two Basque contrasts within the same group of infants. This criterion eliminated 51 infants, 29 from the younger group and 22 from the older group. An additional 12 were excluded due to fussiness (9) and software error (3), leaving a final sample of 93 infants. Two age groups were included in this cross-sectional study: 41 infants aged 6-7 months (27 girls, mean age: 7;0, age range: 6;0-7;6), and 52 infants aged 11-12 months (25 girls, mean age: 11;8, age range: 11;3-12;6).

The present study was conducted according to the ethical research guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. The experiment was approved by the Resaerch Ethics Board of the Basque Center on Cognition, Brain and Language (BCBL). Only infants born full term, with normal hearing, and no known diagnoses of any disorder were invited to participate in our study. Language exposure was assessed using a detailed parental questionnaire which included the number of hours of language exposure, and Basque dialect use by parents and other people in contact with the infant. All infants who were exposed to Basque heard dialects that included our target contrasts, namely, the Gipuzkoan or the Upper Navarresse dialects of Basque (spoken respectively in the provinces of Gipuzkoa and Navarre). Infants with more than 5% overall exposure to any language other than Spanish or Basque were excluded.

2.2. Stimuli

Typically, target consonants are placed in a consonant-vowel (CV) context, but here we used an intervocalic position because the TX-TZ contrast does not occur word-initially. For each disyllable (i.e., *aSu, aZu, aTXu, aTZu*), four tokens were selected from a set of recordings made by three female native speakers of Basque who also spoke Spanish, yielding a total of 12 tokens (four different disyllables from each of the three speakers). Tokens were recorded at a 44.1 kHz sampling rate and were edited using Praat (Boersma, 2002). Separate stimulus files were created for each type of sound, matched for duration (15.9 s), and scaled to 70 dB. Each file consisted of repetitions of four different tokens of one stimulus category produced by a single speaker. Fricative tokens had a mean duration of 489 ms (range = 430–566; average *aSu* duration = 491 ms, average *aZu* duration = 487 ms). The affricate tokens had a mean duration of 534 ms (range = 456–633; average *aTXu* duration = 534 ms, average *aTZu* duration = 534 ms). The F0 values of the three female speakers we recorded for the stimuli ranged between 169-181 Hz. The inter-stimulus-interval was 1000 ms. See Appendix A for details on peak amplitude, spectral centroid and duration. The stimuli are available upon request.

2.3. Procedure

Like Sundara et al. (2008; 2018), we tested infants using the infant-controlled version of the visual habituation procedure, implemented in Habit 2000 software (Cohen, Atkinson, & Chaput, 2000). All infants did two matched experiments, one testing the S-Z fricative contrast and the other testing the TX-TZ affricate contrast. Experiment order was counterbalanced across infants[2]. The infant sat on the caregiver's lap 1.2 meters from a television screen (52", corresponding to 116x65cm) in a sound-attenuated booth. A video camera and speakers were located below the screen. Parents listened to distracter music through headphones to prevent them from influencing the infant's behavior. An experimenter located in a control room observed the infant on a monitor. This experimenter coded the infant's visual fixation pattern during the experiment while listening to music over headphones. Before the onset of each trial, a flashing red light appeared on the screen to attract the infant's attention. Once the infant fixated on the light, a black-and-white checkerboard appeared on the screen accompanied by the auditory stimulus. If the infant looked away for more than 2 s during a trial, the next trial automatically started.

Each experiment included four phases: pre-test, habituation, test, and post-test. Pre- and post-tests were included to monitor infants' general attention level before and after the task. The stimuli in these trials were visually more salient and attractive (a colorful turning wheel accompanied by a female voice repeating the syllable "dah" in an infant-directed way) than the stimuli during the experimental trials. If infants exhibited low looking times during pre- and post-trials (lower than the shortest habituation trial duration, established as 3 s), we inferred that the infant was generally not engaged in the experiment. Therefore, only infants who paid attention during the pre- or post-trials for at least 3 s were included in the analysis. In the current study, no infants were discarded for not paying attention during the pre- and post-test.

During the habituation phase, half of the infants within each age group heard tokens of one category of the target contrast, and the other half heard tokens of the other category. Within each habituation category, tokens were produced by two – of the three – different speakers. The habituation phase continued until the looking time for three consecutive trials dropped below 50% of the looking time for the longest three consecutive trials.

In the test phase, six trials produced by a new talker were presented, based on the same multiple-talker paradigm as Sundara et al. (2008). Half of the infants heard the test trials in an "ABABAB" order, and the other half heard them in a "BABABA" order. "A" trials represent tokens from the novel category not heard during habituation (test trials), and "B" trials represent

[2] Among the 51 infants who were excluded for not finishing two experiments, 10 infants from the younger group and 14 infants from the older group were tested only on the fricative experiment. The rest completed the affricate experiment.

tokens from the familiar category (control trials). If looking times are significantly higher on the test trials than on the control trials, sound discrimination is inferred.

3. Results

Infants of different ages were comparable on pre- and post-test listening times, for both the S-Z fricative contrast (Table 1) and the TX-TZ affricate contrast (Table 2).

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

Data were analyzed using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2013) for linear mixed-effect models in R (R Development Core Team, 2012)[3]. The best fitting model was determined following a forward model selection procedure: predictors and random-effects structure were added incrementally until the fit no longer improved. Likelihood ratio tests determined whether each additional fixed or random factor significantly improved the model fit. The base model included by-subjects and by-items random intercepts, with random slopes for both subjects and items. Models with more complicated random structures failed to converge. Age (6-7-months vs. 11-12-months), Contrast (Fricative vs. Affricate), Trial-Type (Control vs. Test) and percentage of Basque exposure (a numerical variable, based on the parental language questionnaire) were the fixed factors, together with an interaction of Age by Contrast by Trial-Type by Basque exposure, to account for possible interactions among these predictors. Levels of all categorical factors were centered, so the intercept of the model represented the grand mean.

[3] We also ran ANOVAs following the same procedure as Sundara et al. (2008). The results are completely consistent with what we report using the currently preferred linear mixed-effect models.

Listening times to the test items (new vs. control) were analyzed as the dependent variable. Figure 1 shows the average listening times for the two age groups, for the two contrasts, for the Test and Control trials.

INSERT FIGURE 1 HERE

Our main goal is to determine whether Basque exposure during the first year of life leads to improved discrimination of the S-Z and TX-TZ contrasts. To this end, we describe infants' perceptual development within the second half of their first year. In each experiment, discrimination would be reflected in longer listening times on Test trials than on Control trials. In fact, overall, infants did listen longer on Test trials (M=6.4s) than on Control trials (M=6.0s), producing a significant effect of Trial type (Intercept: 6.25, SE: 0.47, β: 0.93, SE: 0.47, t: 1.97, $p < .05$, Cohen's d=0.09). Compared to similar experiments with infants (e.g., Sundara et al., 2008; 2018), the numerical difference between Test and Control is rather small, but the difference was consistent (as the significant effect indicates). For the young infants, listening times for Test trials slightly exceeded those for Control trials for the fricative contrast (Test=6.4s vs. Control=6.0s, Cohen's d=0.09), but not for the affricates (Test=6.8s vs. Control=6.8s, Cohen's d=0.01). Older infants' discrimination for the fricative contrast was virtually the same as the younger infants' (Test: 6.4s, Control: 5.9s, Cohen's d=0.11), and they also listened longer to affricate Test trials (M=6.1s) than to Control trials (M=5.4s, Cohen's d=0.15). Collectively, these trends did not produce a significant interaction of Age by Trial type by Contrast (β: -1.05, SE: 1.83, t: -0.57, $p > .05$).

Given the pattern shown in Figure 1, and the non-significant changes with age in the analyses, we conducted an additional single Bayes independent *t*-test using the *BayesFactor* package (Morey, Rouder, Jamil, & Morey, 2015). Our prior assigned an equal probability of the null and the alternative hypotheses, representing the probable distribution of infants' discrimination based on their exposure to Basque. Using the magnitude of infants' discrimination between test and control conditions as the dependent variable, we find that the null hypothesis (i.e., no difference between conditions) was substantially more likely than the alternative hypothesis. For the fricative contrast, the difference between the two conditions resulted in BF01 = 4.23 for 6-7-month-old infants, and in BF01 = 4.17 for 11-12-month-old infants. For the affricate contrast, Bayes Factor was BF01 = 5.93 for 6-7-month-olds and BF01 = 2.15 for 11-12-month-olds. Thus, the Bayesian analyses show that in three cases, the null hypothesis is 4-6 times more likely than the alternative; in the fourth case, it is over twice as likely. Collectively, these analyses converge with the mixed effects analyses, indicating that infants did not develop the ability to discriminate these Basque contrasts.

Recall that the two standard assumptions of attunement theories are that (1) discrimination should increase as a function of exposure (to Basque, in the current case) during the infants' first year, and (2) during the first half of the first year, infants should be able to discriminate both native and non-native contrasts, regardless of language experience. However, as we noted above, there is evidence that this pattern may not hold for acoustically challenging contrasts (Narayan et al., 2010; but see Sundara et al., 2018).

The population in the Basque Country provides a natural manipulation of the amount of exposure to the two challenging Basque contrasts. Figure 2 presents the discrimination scores (listening time to Test trials *minus* listening time to Control trials) for each infant, plotted against the percentage of the infants' Basque exposure. According to the first assumption of attunement theories, there should be a systematic increase in discrimination scores as the Basque exposure percentage increases, and/or a decrease in discrimination for infants who did not receive exposure to the Basque contrasts. The trend lines shown in each panel make it clear that no such systematic increase or decrease in listening times to the Test items occurred, as all of the trend lines are relatively flat. In fact, in three of the four cases, the trend lines actually are sloped slightly downward. Regarding the second assumption, that within the first months of life infants possess a universal discrimination capacity for all speech contrasts, Figure 2 shows that about half of our 6-7-month-old infants could not discriminate either the fricative or the affricate contrast. Given this failure at 6-7 months, future research should explore how newborns and younger infants perceive these stimuli, to assess the early perceptual abilities of Spanish- and Basque-learning babies.

INSERT FIGURE 2 HERE

Overall, based on these results we cannot say that being in an environment with more Basque exposure enabled infants to learn Basque sibilant contrasts by 11-12 months of age. The pattern was similar for the two contrasts, with no interaction of Basque exposure by Contrast by Trial type (β: 0.02, SE: 0.01, t: 1.56, p >.05). The only significant interaction of Basque exposure with other factors was the interaction of Basque exposure by Contrast (β: 0.02, SE: 0.01, t: 2.34, p <.03). The patterns in Figure 2 suggest that this interaction is driven by the relatively flat lines for the S-Z contrast when the two age groups are averaged together, versus the consistently negative slope for the affricate contrast. Looking at the test cases individually, neither young infants nor older ones show any correlation between exposure to Basque and the capacity to distinguish the fricative contrast (6-7-month-olds: r=-0.08, t(40)=0.49, p>.05, 11-12-month-olds: r=0.12, t(51)=0.82, p>.05) or the affricate contrast (6-7-month-olds: r=-0.27, t(40)=1.75, p>.05, 11-12-month-olds: r=-0.2, t(51)=1.44, p>.05). Note that the largest of these (non-significant) correlations (-0.27), if real, would mean that hearing less Baque input is associated with better discrimination of the Basque TX-TZ contrast, the opposite of what would be expected. Thus, while acknowledging that null effects should be treated cautiously (hence, our use of Bayesian tests), we see no evidence in these correlations of the development of an ability to discriminate the contrasts.

4. Discussion

Here, we assessed the discrimination of two Basque sibilant contrasts in 6-7- and 11-12-month-old infants who varied in their amount of exposure to Basque. Overall, infants demonstrated a capacity (even if it was a small effect size) to discriminate these difficult contrasts. Basque adult speakers find these fricative (Larraza et al., 2016) and affricate (Samuel & Larraza, 2015) contrasts to be more subtle than some others, and this study shows that infants show a limited capacity to discriminate them within the first year of life.

Our findings, together with those from other studies (Best, 1991; Best, McRoberts, & Sithole, 1988; Eilers, Wilson, & Moore, 1977; Narayan, Werker, & Beddor, 2010; Polka & Bohn, 1996; Sato, Sogabe, & Mazuka, 2010), suggest that discussion of attunement theories should be more nuanced than it often is. First, infants who do not receive exposure to a given consonant contrast do not always decline in their ability to discriminate the contrast by the end of their first year (Best et al., 1988; Polka et al., 2001). Second, for perceptually subtle contrasts, prolonged exposure to the native language may be required, as the distinction between the two phonemes is not always salient in early development. Prior studies support this view for fricative perception; discrimination of fricatives develops later than perception of stop consonants, for instance (e.g., Eilers, 1977; Eilers et al., 1977).

The discrimination performance of Spanish-dominant infants did not decline during a year with little exposure to the critical contrasts, contrary to the second basic assumption of attunement theories. Our results add new data to previous studies that report no perceptual decline in the discrimination of non-native contrasts during the first year of life (e.g., Best et al., 1988; Polka et al., 2001). It might be the case that these infants assimilated the Basque sounds to Spanish consonant categories, facilitating their discrimination abilities at 11-12 months of age. Spanish-dominant infants could focus on their native fricative and affricate phonemes (/s̺/, /tʃ/), which would in principle allow the novel (Basque) phonemes (fricative /s̻/, affricate /ts̻/) to be distinguished as contrasting with the familiar phones. Perceiving non-native contrasts as deviant exemplars of a native consonant is classified as a Category Goodness assimilation type in Best's (1995) Perceptual Assimilation Model. We have no basis to test this possibility, so at least in principle it might provide a force to counter the loss in discrimination that would be expected on the basis of attunement theory.

Contrary to the core expectation of attunement theories, our results show no facilitative effect of language-specific experience by the end of the first year. Increased exposure to Basque did not result in higher discrimination scores, for either contrast, by 11-12 months of age. There is, of course, considerable evidence from prior research that language-specific experience does increase infants' sensitivity to native speech sounds (e.g., Kuhl et al., 2006; Narayan et al., 2010; Tsao, Liu, & Kuhl, 2006). Critically, however, in some cases the facilitative effect of native language experience occurs later than 11-12 months. Polka et al. (2001) tested infants and adults with English and French language backgrounds on discrimination of the English /d/-/ð/ (voiced stop versus voiced non-sibilant fricative) contrast. French-speaking adults' discrimination of the contrast was much worse than the English-speaking adults', as predicted. However, 10-12-month-old English- and French-learning infants did not differ in their discrimination abilities. By 4 years of age, the situation was different and the predictions of attunement theories were borne out: English-learning, but not French-learning, children improved their perceptual sensitivity to the English /d/-/ð/ contrast (Sundara, Polka, & Genesee, 2006). Furthermore, English-French bilingual children, but not adults, showed lower discrimination than their English peers, suggesting that accumulating language experience throughout the life span facilitates the perception of certain speech sounds.

It seems likely that the difficult Basque fricative and affricative contrasts also have a delayed acquisition process, akin to what seems to be the case for the English /d/-/ð/ contrast. If so, then if 4 year-old Basque- and Spanish-learning children were tested on the current stimuli, possibly Basque but not Spanish children would show discrimination. However, Basque children would not probably perform as accurately as L1 Basque adults, based on the effect of prolonged exposure to the native language (Sundara et al., 2006).

As noted above, the acquisition (and loss) of many contrasts can be accommodated nicely by attunement theories: Lack of exposure can lead to a decline in the discrimination of non-native consonants by the end of the first year (Tsushima et al., 1994; Werker & Tees, 1984), and exposure can facilitate the discrimination of speech sounds during the first year of life (e.g., Sundara et al., 2006; Narayan et al., 2010). However, our results, and the results of several other studies, suggest that when exposure to the native language interacts with other important variables (small acoustic-perceptual distance, low frequency of the critical phonemes, frequent mispronounciations of the sounds, dialectal variability, etc.), some contrasts will follow another path. As we noted, for certain contrasts, no perceptual decline is observed in infancy or adulthood, despite a lack of exposure (e.g., Best, 1991; Polka & Bohn, 1996). Here, we report a different developmental pattern: For the Basque sibilants, discrimination remains steady and rather poor throughout the infant's first year. Young infants (6-7-months), who should be sensitive to all speech contrasts according to attunement theories, discriminate the Basque consonants just as poorly as the 11-12-month olds. Moreover, increased exposure in the first year did not improve perception: Spanish-Basque bilingual and Basque-dominant infants showed no better discrimination than Spanish-dominant infants.

Regarding the intrinsic phonetic-perceptual salience of each of the tested contrasts, the within-subjects design we employed gave us the opportunity to explore whether the acoustic and articulatory properties of these contrasts affect how these phonological categories are built. We postulated that based on its articulatory features, the affricate contrast should be perceptually more salient than the fricative one. However, our results show no facilitation in the perception of the TX-TZ sounds relative to the S-Z sounds. The distributional learning mechanisms that organize the acoustic space bimodally or unimodally, depending on the input infants receive, do not seem to be sufficiently sensitive for these subtle contrasts.

Certainly, not all phonemic contrasts follow the same developmental pattern. Although adult Basque-speakers are of course able to use the fricative and afficate contrasts in their native language, these contrasts still are not as well discriminated as most others (Larraza et al., 2016; Samuel & Larraza, 2015). Our results demonstrate that for these difficult sounds, a "low and flat" discrimination pattern is seen across the first year, indicating that inherent acoustic-phonetic and perceptual difficulty of some contrasts must be slowly overcome by prolonged native language experience and increased age. A full explanation of how speech perception abilities emerge must be informed by study of languages and contrasts not explored previously. The Basque sibilants studied here provide new test cases, ones that involve relatively difficult contrasts that must be learned. Our results reinforce the need to consider a wide range of learning trajectories, an emerging view within theories of language perceptual development.

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FIGURE 1

Average listening time (s, ±SE) to Control and Test trials for 6-7-month-old and 11-12-month-old infants.

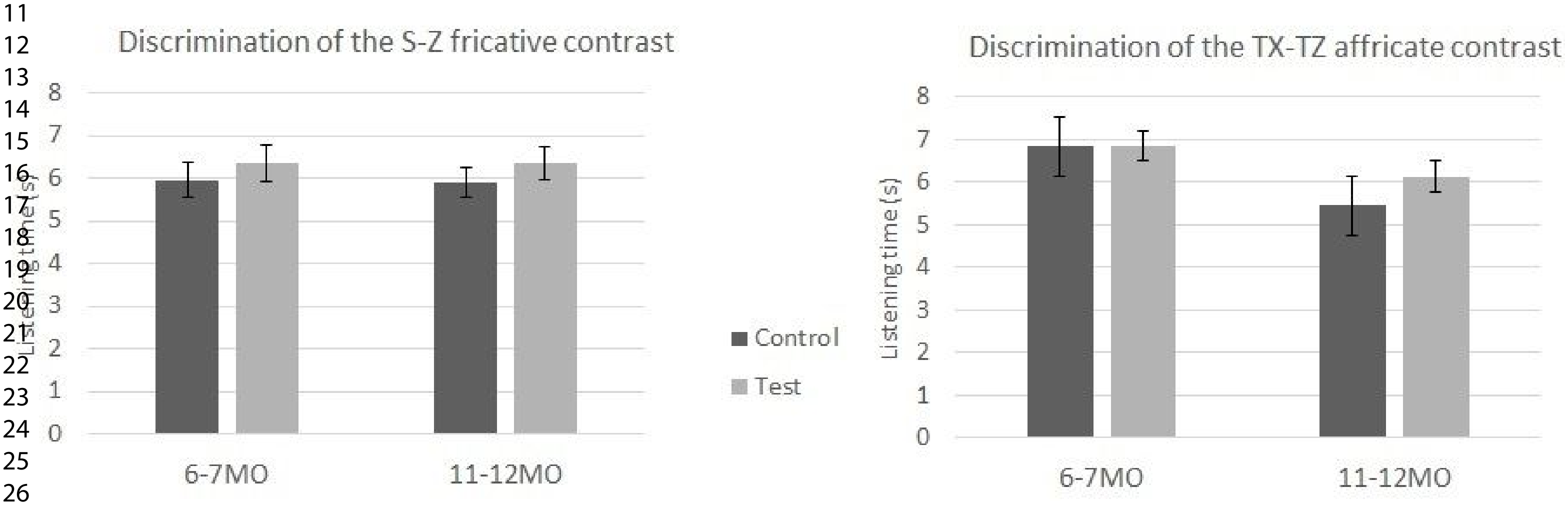


FIGURE 2

Correlation between infants' exposure of Basque and their discrimination scores in the S-Z fricative and the TX-TZ affricate contrasts, separated by age. Discrimination score quantifies how much longer infants listened to Test trials in comparison to Control trials.

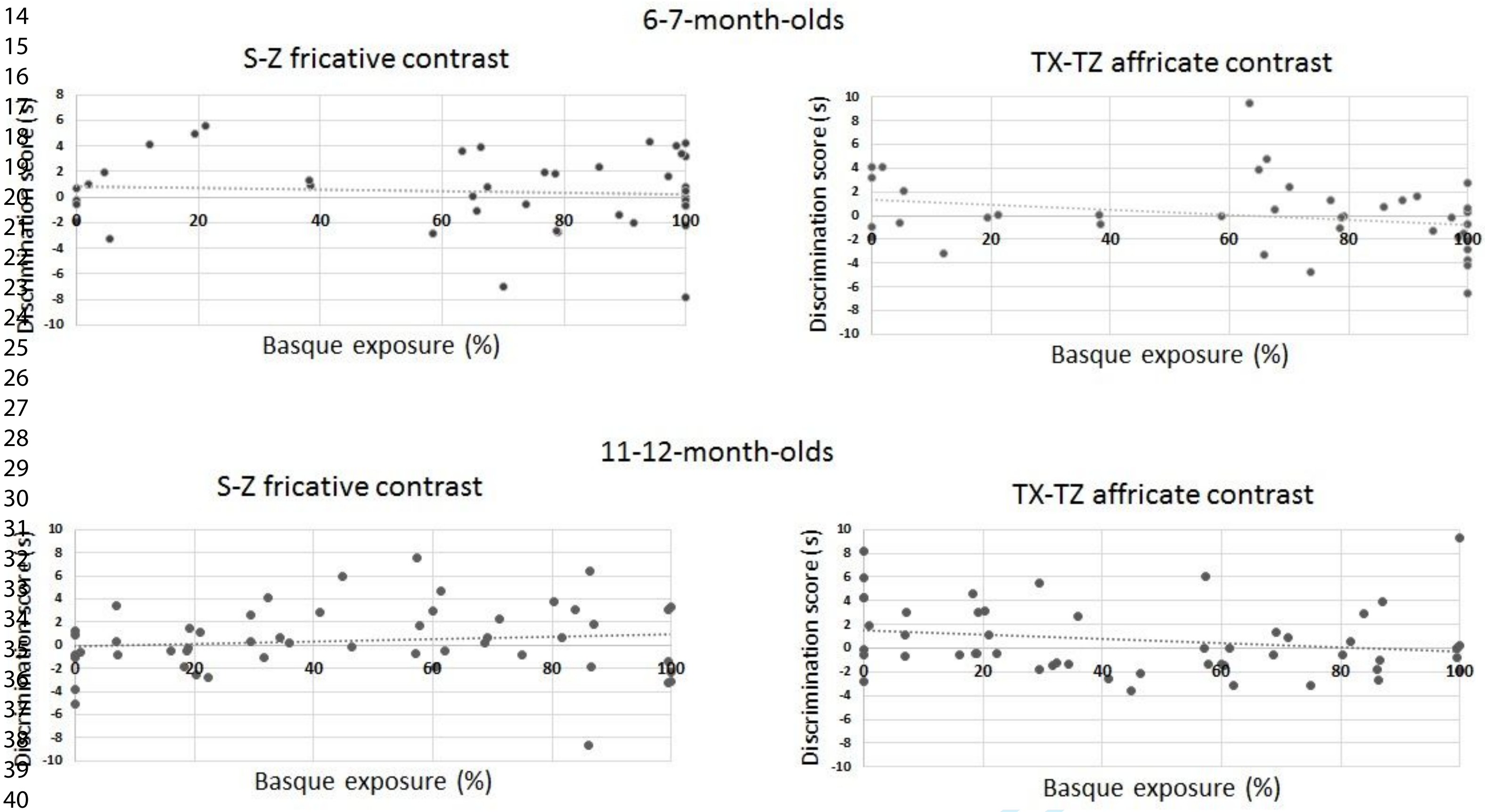


TABLE 1

Average listening times (s, ±SE) to habituation, pre-test, post-test stimuli and number of trials to habituate in the S-Z fricative contrast.

S-Z fricative contrast		
	6-7-month-olds	**11-12-month-olds**
Pre-test	15.2 (0.3)	14.9 (0.4)
Habituation time	79.1 (7.3)	58.6 (3.8)
Trials to habituation	7.9 (0.5)	7.0 (0.4)
Post-test	15.5 (0.4)	15.3 (0.3)

TABLE 2

Average listening times (s, ±SE) to habituation, pre-test, post-test stimuli and number of trials to habituate in the TX-TZ affricate contrast.

TX-TZ affricate contrast		
	6-7-month-olds	**11-12-month-olds**
Pre-test	15.7 (0.1)	15.1 (0.3)
Habituation time	68.2 (7.6)	56.0 (4.1)
Trials to habituation	7.4 (0.5)	6.9 (0.4)
Post-test	14.8 (0.4)	15.1 (0.4)

APPENDIX A

Acoustic characteristics of the Basque S-Z and TX-TZ sounds.

Larraza et al., 2016

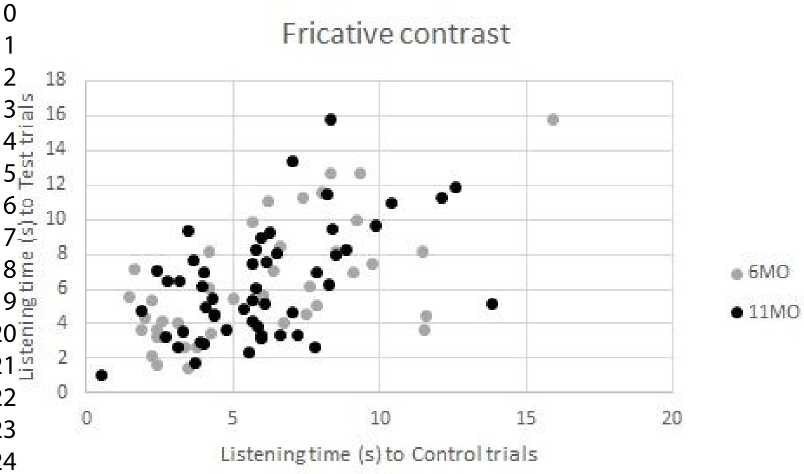
	S	Z	t – value p value
Peak amplitude (dB)	M=69.8 (SD=4.8)	M=62.7 (SD=5.6)	t(79)=9.5 p<.001
Spectral centroid (Hz)	M=5292 (SD=638.5)	M=9437 (SD=1554.2)	t(79)=26.6 p<.001
Duration (ms)	M=156.6 (SD=0.018)	M=168.9 (SD=0.026)	t(79)=3.6 p<.001

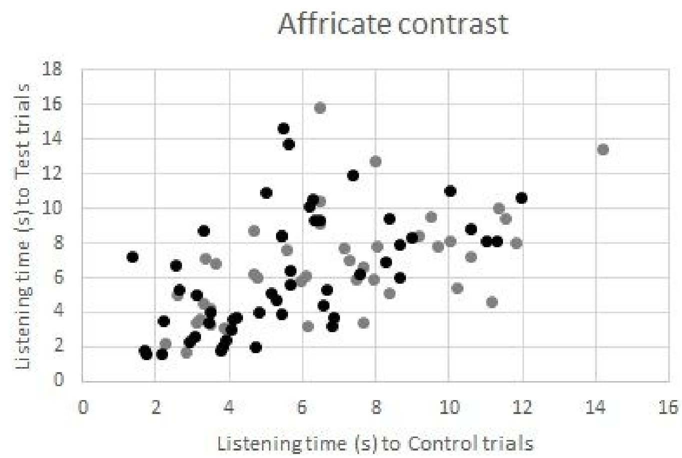
Samuel & Larraza, 2015

	TX	TZ	t – value p value
Peak amplitude (dB)	M=57.8 (SD=7.4)	M=61.8 (SD=6.6)	t(39)=2.6 p<.02
Spectral centroid (Hz)	M=5850.3 (SD=389.7)	M=9506.9 (SD=1201.1)	t(39)=21.3 p<.001
Duration (ms)	M=135.2 (SD=0.019)	M=140.7 (SD=0.015)	t(39)=1.4 p>.05

APPENDIX B

The current figures represent points for individuals' performance across the two contrasts of interest, complementary to the average listening times showed in Figure 1.





APPENDIX C

Appendix C reports the results of an analysis done following the same procedures as in Sundara et al. (2008), creating three different groups of infants (Basque dominant, Spanish dominant and Spanish-Basque bilingual infants). Infants with exposure to Basque or Spanish at least 75% of the time were considered Basque- or Spanish-dominant, respectively. The criterion for including infants in the bilingual group was a minimum of 25% exposure to Basque and Spanish, with both languages being spoken in family settings.

	6-7-month-olds			*11-12-month-olds*		
	Basque-dominant	*Spanish-dominant*	*Sp-Bq Bilingual*	*Basque-dominant*	*Spanish-dominant*	*Sp-Bq Bilingual*
N	*15*	*15*	*11*	*15*	*18*	*19*

The base model included by-subjects and by-items random intercepts and random slopes for both. Age (6-7-months vs. 11-12-months), Group (Basque vs. Spanish vs. Bilingual), Contrast (Fricative vs. Affricate) and Trial-Type (Familiar vs. Novel) were the fixed factors, together with an interaction of Age by Group by Contrast by Trial-Type. Listening time was analyzed as the dependent variable.

For the fricative contrast, 11-12-month-old bilingual infants listened significantly longer to novel trials (6.5 s) than to familiar trials (5.3 s), leading to a significant interaction of age by group by contrast by trial-type (Intercept: 7.63, SE: 0.9, β: 5.39, SE: 2.38, t: 2.27, $p < .05$). However, this difference was not significant for 11-12-month-old Basque infants (familiar: 6.3 s, novel: 6.6 s, β: 1.65, SE: 2.37, t: 0.7, $p > .05$), nor for 11-12-month-old Spanish infants (familiar: 5.8 s, novel: 5.6 s, Intercept: 6.62, SE: 0.82, β: -1.65, SE: 2.37, t: 0.7, $p > .05$). Regarding the younger age, 6-7-month-old infants listened longer to novel trials, but this difference was not enough to reach significance, as the lack of interaction of age by trial-type indicates (β: 2.04, SE: 1.13, t: 1.8, $p > .05$). The slightly longer listening times of young infants (6.46 s) in comparison to the old ones (5.99 s) did not significantly differ (β: -1.86, SE: 1.09, t: -1.71, $p > .05$).

For the affricate contrast, only Spanish 11-12-month-olds showed discrimination between Basque TX and TZ sounds (Intercept: 5.01, SE: 1.04, β: 5.39, SE: 2.38, t: 2.27, $p < .05$). This was not the case for infants who had larger exposure to Basque: 11-12-month-old Basque infants (β: 3.74, SE: 2.48, t: 1.51, $p > .05$) or for bilingual infants (Intercept: 6.21, SE: 0.86, β: -3.74, SE: 2.48, t: -1.51, $p < .05$). Younger Spanish infants did not distinguish the two affricate consonants (Intercept: 6.4, SE: 0.88, β: -1.65, SE: 2.4, t: -0.7, $p < .05$). The same was true for Bilingual 6-7-month-olds (β: 3.74, SE: 2.48, t: 1.51, $p > .05$), and Basque 6-7-month-olds (Intercept: 5.81, SE: 0.82, β: 1.65, SE: 2.4, t: 0.7, $p > .05$).

APPENDIX D

In the test phase of our visual habituation tasks, infants were presented with three trials (consisting of one control item and one test item each). To examine whether infants' attention decreased during the test, obscuring any ability to discriminate between the two consonants, we analyzed the first, and the first two test trials separately. These analyses complement those in the main text, in which overall performance across the all three trials was analyzed. Overall, looking at all three test trials together was more sensitive that looking at these subsets: The significant effect of trial type reported in the main text did not appear in the partial analyses reported below. This means that far from being tired or not responsive during the three trials, our infants were engaged during the experiment.

● Results of an analysis that only included **one test trial** (one control item, one test item) from the test phase, showing the effects for each of the variables of interest and interactions among them:

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	7.447645	0.745532	7.24	9.990	0.0000171	***
age1	-0.901549	1.210581	95.19	-0.745	0.4583	
Bq.exp	-0.005837	0.009854	17.03	-0.592	0.5614	
contrast1	-1.419641	1.274417	3.97	-1.114	0.3281	
trial.type1	0.781476	0.788185	175.71	0.991	0.3228	
age1:Bq.exp	-0.010740	0.018305	91.98	-0.587	0.5588	
age1:contrast1	1.561334	1.925721	91.59	0.811	0.4196	
Bq.exp:contrast1	0.020708	0.016064	8.30	1.289	0.2321	
age1:trial.type1	1.494469	1.525658	175.73	0.980	0.3287	
Bq.exp:trial.type1	-0.002490	0.011574	174.93	-0.215	0.8299	
contrast1:trial.type1	-1.452755	1.576409	175.71	-0.922	0.3580	
age1:Bq.exp:contrast1	-0.009446	0.028960	90.28	-0.326	0.7450	
age1:Bq.exp:trial.type1	-0.003057	0.023015	176.08	-0.133	0.8945	
age1:contrast1:trial.type1	0.943457	3.051365	175.73	0.309	0.7575	
Bq.exp:contrast1:trial.type1	0.042312	0.023149	174.93	1.828	0.0693	
age1:Bq.exp:contrast1:trial.type1	-0.010709	0.046029	176.07	-0.233	0.8163	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

● Results of an analysis that included 2 test trials and 2 control trials from the test phase (as in Sundara et al., 2008), showing the effects for each of the variables of interest and interactions among them:

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	6.708250	0.529887	20.5	12.660	0.0000000000376	***
age1	-0.326325	0.981483	96.6	-0.332	0.7402	
Bq.exp	-0.002663	0.007912	13.7	-0.337	0.7415	
contrast1	-1.674971	0.781304	7.1	-2.144	0.0686	

```
trial.type1                          0.663677 0.578860 544.6  1.147 0.2521
age1:Bq.exp                         -0.013281 0.014884 93.1  -0.892 0.3745
age1:contrast1                       1.223518 1.421583 90.7   0.861 0.3917
Bq.exp:contrast1                     0.019527 0.011787 4.7   1.657 0.1625
age1:trial.type1                    -0.145803 1.120414 545.3  -0.130 0.8965
Bq.exp:trial.type1                  -0.001115 0.008533 545.0  -0.131 0.8961
contrast1:trial.type1               -1.378554 1.156982 544.6  -1.192 0.2340
age1:Bq.exp:contrast1                0.003799 0.021407 90.2   0.177 0.8595
age1:Bq.exp:trial.type1              0.014560 0.016929 545.9   0.860 0.3901
age1:contrast1:trial.type1          -1.855783 2.239362 545.3  -0.829 0.4076
Bq.exp:contrast1:trial.type1         0.032522 0.017054 545.0   1.907 0.0570
age1:Bq.exp:contrast1:trial.type1 0.034547 0.033835 545.9  1.021 0.3077
---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```