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The effects of prematurity and socioeconomic deprivation on early speech perception: A story of two different delays

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Abstract

There is evidence showing that both maturational and environmental factors can impact on later language development. On the one hand, preterm birth has been found to increase the risk of deficits in the preschool and school years. Preterm children show poorer auditory discrimination, reading difficulties, poor vocabulary, less complex expressive language and lower receptive understanding than their matched controls. On the other hand, socioeconomic status (SES) indicators (i.e., income, education and occupation) have been found to be strongly related to linguistic abilities during the preschool and school years. However, there is very little information about how these factors result in lower linguistic abilities. The present study addresses this issue. To do so, we investigated early speech perception in full and preterm infants from families classed as high or low SES. Seventy-six infants were followed longitudinally at 7.5, 9, 10.5 and 12 months of age. At each test point, three studies explored infants' phonetic, prosodic and phonotactic development respectively. Results showed no significant differences between the phonetic or the phonotactic development of the preterm and the full-term infants. However, a time-lag between preterm and full-term developmental timing for prosody was found. Socioeconomic status did not have a significant effect on prosodic development. Nonetheless, phonetic and phonotactic development was affected by SES, infants from lower SES showed phonetic discrimination of non-native contrast and a preference for high-probability sequences later than their more advantaged peers. Overall these results suggest that different constraints apply to the acquisition of different phonological subcomponents.

KEYWORDS

phonetics, phonological acquisition, phonotactics, preterm infants, prosody, SES, speech perception

1 | INTRODUCTION

Research highlights

- Preterm birth and socioeconomic status (SES) affect early speech perception. Evidence of delays was found as early as 10.5 months of age.
- Maturational and environmental factors have different effects on each phonological subcomponent.
- Prematurity altered infants' prosodic development, but not phonetic or phonotactic development.
- Low SES delayed phonetic and phonotactic development, but not prosodic development.
- Different constraints apply to the acquisition of different phonological subcomponents.

Language delay can compromise children's readiness for school, as well as academic performance as they move through the school years. Language delay at school entry is linked to later health and social inequalities (Maggi, Irwin, Siddiqi, & Hertzman, 2010; The Marmot review, Marmot et al., 2010). While some children outgrow their language delay, for many others it appears to have a detectable impact well into adulthood, not just on subsequent language skills but on literacy, quality of life, mental health and professional success (Councils, 2011; Field, 2010; Hartshorne, 2006; Law, 2019; Law, Charlton, & Asmussen, 2017a; Law, Charlton, Dockrell, et al., 2017b; Law & Elliott, 2009; Maggi et al., 2010; Ruben, 2000; The Marmot review, Marmot et al., 2010). Among others, preterm birth and socioeconomic deprivation have been identified to significantly increase the risk of developing language delays during the school years. Preterm children and those from low-SES backgrounds have both been shown to have poorer language processing, reading difficulties, lower receptive understanding, poor vocabulary and less complex expressive language than their preschool peers (for effects of prematurity see: Briscoe, Gathercole, & Marlow, 1998; Crunelle, Le Normand, & Delfosse, 2003; Grunau, Kearney, & Whitfield, 1990; Grunau, Whitfield, & Davis, 2002; Guarini et al., 2009, 2010; Hack et al., 1994; Jansson-Verkasalo et al., 2004; Luoma, Herrgård, Martikainen, & Ahonen, 2008; Pritchard et al., 2009; Sansavini et al., 2010; for effects of SES see: Fernald, Marchman, & Weisleder, 2013; Halle et al., 2009; Lee & Burkam, 2002; Nelson, Welsh, Trup, & Greenberg, 2011; Ramey & Ramey, 2004; Raviv, Kessenich, & Morrison, 2004; Ruben, 2000). In fact, there is evidence suggesting that 30% of children born preterm and 65% of preschoolers from lower socioeconomic status (SES) families have clinically significant language delays (Briscoe et al., 1998; Raviv et al., 2004). Although problems in these groups are well recognized, there is scant information about the mechanisms behind these language delays. Given the evidence suggesting that these differences are already well established by 4 years of age (Nelson et al., 2011), it becomes imperative to focus on the very early stages of language development. Accordingly, the present study compares the speech perception trajectory in preterm and full-term infants from low- and high-SES backgrounds, focusing on three different aspects: prosody (i.e., suprasegmental perceptual narrowing for non-native lexical tones), phonetics (i.e., segmental perceptual narrowing for a non-native consonant contrast) and phonotactics (i.e., sensitivity to the frequency of phoneme sequences). Phonological development was chosen as this is one of the earliest stages of language development in which key skills for later stages are mastered (Kuhl, 2000; Yeung, Chen, & Werker, 2013).

Within the phonological domain, studies have established that infants start learning the prosodic (e.g., Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009; Jusczyk, Cutler, & Redanz, 1993), phonetic (e.g., Kuhl et al., 2006; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 1984) and phonotactic (e.g., Friederici & Wessels, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Sebastián-Gallés & Bosch, 2002) properties of their native language well before their first birthday. Three major developmental milestones have been identified as markers of infants' specialization towards their native language. First, there is an increase in infants' ability to process native sounds (e.g., Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993) and native prosodic information (e.g., Höhle et al., 2009). Second, infants show a preference for phoneme sequences or prosodic patterns that are either legal (vs. illegal) or have a high probability of occurrence (vs. low probability) in their native language (e.g., Jusczyk, Cutler, et al., 1993; Jusczyk et al., 1994). Third, infants' ability to process non-native sounds decreases over time (e.g., Kuhl et al., 1992; Werker & Tees, 1984). These are all part of a process known as *perceptual narrowing* in which infants' ability to process non-native contrasts decreases, while their ability to process native contrasts increases. Phonological perceptual narrowing has been considered to be the first sign that infants are acquiring their native language (Tsuji & Cristia, 2014).

Lexical tone has been used to study infants' suprasegmental (i.e., speech features such as stress, tone or intonation that are added over consonants and vowels, and which extend over syllables, words or phrases) perceptual narrowing to non-native contrasts. Lexical tone refers to the distinctive pitch level carried by a syllable of a word, which is used to distinguish meaning. A study testing English-learning full-term infants' ability to discriminate Thai non-native lexical tone contrasts (Mattock & Burnham, 2006) showed the typical pattern of maintenance and decline in prosodic speech perception: American English-learning infants discriminated the Thai tone contrast at 6 but not at 9 months of age, while Mandarin learning infants discriminated the tone contrast at both ages. These results show evidence of suprasegmental perceptual narrowing. A few studies have explored early prosodic capacities in very preterm infants. Two studies explored linguistic rhythm discrimination (Bosch, 2011; Peña, Pittaluga, & Mehler, 2010), and another one examined stress pattern discrimination (Herold, Höhle, Walch, Weber, & Obladen, 2008). These studies conclude that performance of preterm infants is indexed by their maturational age (corresponding to their chronological age minus the duration of their prematurity) rather than by their chronological age (calculated from the infant's birth). Indeed, very preterm infants (MGA = 28.6 weeks) were found to have acquired distinctions specific to their native language that allow them to distinguish their native language from another rhythmically similar language at 9 months of age (6 months corrected age), while full-term infants were able to make this distinction by the age of 6 months[1] (Peña et al., 2010). Similarly at 4 months of age (7 months corrected age) both very preterm (MGA = 28.8 weeks) and full-term Spanish learning infants were able to discriminate their native language from a non-familiar language belonging to a different rhythmic class (i.e., English; Bosch, 2011). By 6 months of age (9 months corrected age), they were both able to discriminate their native language from a language belonging to the same rhythmic class (i.e., Catalan). Moreover, 4- and 6-month-old (corrected age) German very preterm (MGA = 27.6 weeks) infants were not able to distinguish between a trochaic stress pattern (stress on the first syllable), which is characteristic of German words, and an iambic stress pattern (stress on the second syllable), whereas full-term infants do so at both 4 and 6 months of age (Herold et al., 2008). The above results suggest that the development of prosodic processing in preterm infants is affected during the first year of life.

At the segmental level (i.e., consonantal or vocalic segments of words), phonetic perceptual narrowing was first shown by Werker and Tees (1984). Early phonetic development was explored by testing English-learning infants' ability to discriminate Hindi and Salish non-native contrasts. The results of the study showed that 6–8-month-olds, but not 8–12-month-olds could distinguish both non-native contrasts. However, 10–12-month-old Hindi- and Salish-learning infants were able to discriminate their native contrasts respectively (c.f. Kuhl et al., 2006 for similar results in Japanese-learning infants). These results establish the existence of early developmental changes regarding the way infants perceive speech sounds. Jansson-Verkasalo et al. (2010) studied early phonetic development in very preterm infants (MGA = 29 weeks). This study found that the amplitude of the mismatch negativity (MMN) response to a non-native vocalic phoneme contrast (i.e., Estonian vowel) diminished between 6 and 12 months of age in full-term Finnish-learning infants, but not in infants born very preterm, who showed no evidence of perceptual narrowing. Similarly, Figueras and Bosch (2010) explored very preterm (MGA = 29.5 weeks) infants' ability to perceive and discriminate a native vowel contrast (i.e./o–u/). Their results showed that very preterm infants were only able to discriminate this vocalic contrast at 8 months corrected age, but not at 4 months, when full-term infants start showing discrimination. Taken together, these results show a delay in very preterm infants' vocalic discrimination compared to infants born full term. Interestingly, using a MMN paradigm with phonetic deviants, Kostilainen et al. (2020) found no significant differences in the neural processing of native vocalic sound changes (phonetic deviants included changes in vowel duration/ta-ta:/, vowel change/ta-to/, intensity ± 6 dB and frequency ± 25.5 Hz) between very and moderate preterm (MGA = 30.5 weeks) and full-term infants at term (i.e., 40 weeks GA).

Other studies have also shown that by 9 months of age infants become attuned to the phonotactic properties of their native language. Nine-month-old American English-learning infants preferred to listen longer to a list of words corresponding to the phonetic and phonotactic structure of their language rather than to a list of words with a structure of another language (Jusczyk, Friederici, et al., 1993; Sebastián-Gallés & Bosch, 2002); and they showed a preference for sound sequences with a high-phonotactic probability in their language, compared with sound sequences that exhibit a low probability (Jusczyk et al., 1994). A single study has explored early phonotactic sensitivity in very preterm (M_{GA} = 29.7 weeks) French-learning infants (Gonzalez-Gomez & Nazzi, 2012). At 10 months of chronological age, both preterm and full-term infants showed a preference for sequences having a higher probability of occurrence (e.g., 'bat' or 'pad') compared to sequences having a lower probability of occurrence (e.g., 'tab' or 'dap'). This suggests that preterm developmental timing for phonotactic acquisition is based on chronological age (experience with input) rather than on maturational age, so no difference between the preterm and the full-term infants' phonotactic development was found.

Taking together these results show that some but not all aspects of early speech perception are affected by preterm birth. To our knowledge, there are no data regarding the developmental trajectory of early phonological acquisition in infants from lower-SES families. But, a study investigated vocabulary and language processing in 18-month-olds from higher- and lower-SES families (Fernald et al., 2013). SES groups were determined using the Hollingshead Four Factor Index of Socioeconomic Status (HI, Hollingshead, 1975). The HI is a survey designed to measure the social status of an individual based on four domains: marital status, retired/employed status, educational attainment and occupational prestige. Their results showed significant disparities in vocabulary and language processing efficiency at 18 months between infants from higher- and lower-SES families. The authors also found a 6-month gap between SES groups in processing skills critical to language development at 24 months of age.

Although there is a considerable amount of information regarding the effects of prematurity and SES on language development, both the origin of such language difficulties and the effect of these factors on early language development are for the most part unknown. The present study aimed to better understand the interplay between physical/cognitive maturation and environmental exposure to language in early language development. To do this, infants' early speech development was investigated in populations showing maturational and/or environmental differences: infants born preterm or full-term from lower- or higher-SES backgrounds. Testing these populations can shed complementary light on the complex interplay between maturational and environmental factors that occurs during early language acquisition. Accordingly, infants born preterm or full term from lower- or higher-SES backgrounds were tested on three experiments (i.e., prosody, phonetics and phonotactics) longitudinally at 7.5, 9, 10.5 and 12 months of chronological age. It is important to highlight that the prosody and the phonetics discrimination tasks both measured the loss of non-native contrasts, while the phonotactic task measured increase in the capacity to discriminate native contrasts. Thus, these tasks measure different aspects of language development not only in terms of the domain they test but also in terms of the process (i.e., loss vs. increase).

Based on previous findings (e.g., Bosch, 2011; Herold et al., 2008; Peña et al., 2010), we expect a delay in preterm infants' perceptual narrowing for non-native lexical tones (i.e., prosody). Accordingly, preterm infants will lose their ability to discriminate this non-native contrast later than their full-term peers. However, based on Gonzalez-Gomez and Nazzi's results (2012) no differences are expected between preterm and full-term infants' perceptual narrowing for non-native consonant contrasts (i.e., phonetics) or infants' sensitivity to the frequency of phoneme sequences (i.e., phonotactics). Thus, preterm and full-term infants will show a decrease in their ability to discriminate the non-native consonant contrast and an increase in their sensitivity to high-probability sequences at a similar age than their full-time peers (see Figure 1). However, there is not enough information to predict whether or not infants from lower-SES families would show a delay and whether or not maturational and SES effects are additive.

2 | MATERIALS AND METHODS

2.1 | Participants

The data of 38 preterm English-learning infants were included in the analyses. Infants were followed longitudinally at 7.5, 9, 10.5 and 12 months of chronological age ($M_{7.5m}$ = 7;21; range: 7;01–8;00; M_{9m} = 9;5; range: 9;00–9;18; $M_{10.5m}$ = 10;19; range: 10;00–11;01; M_{12m} = 12;06; range: 12;01–12;18; 19 girls, 19 boys). Preterm infants were recruited if, at birth, they had met five primary criteria: (a) a gestational age ≤ 33 weeks, (b) the absence of major cerebral damage (e.g., periventricular leukomalacia (PVL), intraventricular haemorrhage (IVH), hydrocephalus, retinopathy of prematurity (ROP) and congenital malformations, (c) no indication of visual or hearing impairment (d) birth weight <2,000 g and (e) born in monolingual English-speaking families. Preterm infants mean gestational age at birth was 29.4 weeks (*SD* = 2.40), with a range from 26 to 33 weeks, and their mean birth weight was 1,455 g (*SD* = 388) with a range from 700 to 1,980 g. The sample included 20 infants from higher-SES families and 18 infants from lower-SES families. It is important to highlight that no significant differences were found between infants from higher-SES and lower-SES families in terms of gestational age ($t(36) = 0.50$, $p = .62$) or birth weight ($t(36) = -0.31$, $p = .76$) The data of four additional preterm infants were excluded due to fussiness (3) or not completing the four sessions (1).

Thirty-eight healthy full-term English-learning infants were recruited and their data included in the analyses. Similarly, infants were followed longitudinally at 7.5, 9, 10.5 and 12 months of chronological age ($M_{7.5m}$ = 7;18; range: 7;02–8;00; M_{9m} = 9;6; range: 9;02–9;26; $M_{10.5m}$ = 10;17; range: 10;00–11;01; M_{12m} = 12;06; range: 12;03–12;25; 18 girls, 20 boys) All full-term infants have experienced normal Term (gestational age > 37 weeks and Term weight > 2,800 g), and had no history of major cerebral damage and/or congenital malformations or visual or hearing impairments. The sample included 20 infants from higher-SES families and 18 infants from lower-SES families. The data of 11 additional full-term infants were excluded due to fussiness (8) and not completing the four sessions (3).

2.1.1 | Socioeconomic status

Families lived in areas spanning the full range of the 2015 English Indices of Multiple Deprivation (IMD), a measure provided by the UK Office of National Statistics based on neighbourhood employment, income, health provision and housing. One third of families lived in areas with a score in the bottom three IMD deciles (*N* = 26), a further 26% lived in deciles 4–6 (*N* = 20), with the remaining 39% living in deciles 7–10 (*N* = 30). Caregivers' level of education spanned the full range of the European Qualifications Framework: 38% of primary caregivers had a postgraduate degree, 25% had a degree, while the remainder 37% did not. Thirty-two per cent of families reported incomes below £28,000 (UK median). A principal components analysis (*N* = 76) confirmed that IMD rank, primary caregiver education and annual income collapsed onto one factor and this factor (centred, scaled and reversed such that a positive score represents higher SES and a negative score lower SES) was used in the analyses.

The final sample included 20 preterm infants from high-SES families, 18 preterm infants from low-SES families, 20 full-term infants from high-SES families, and 18 full-term infants from low-SES

	Prosody				Phonetics				Phonotactics			
	7.5m	9m	10.5m	12m	7.5m	9m	10.5m	12m	7.5m	9m	10.5m	12m
FT H-SES	✓	x	x	x	✓	?	x	x	x	?	✓	✓
FT L-SES	✓	?	?	x	✓	?	?	?	x	?	?	?
PT H-SES	✓	✓	✓	x	✓	?	x	x	x	?	✓	✓
PT L-SES	✓	✓	✓	?	✓	?	?	?	x	?	?	?

FIGURE 1 Summary of the different developmental trajectories predicted for each of the language subcomponents (i.e., prosody, phonetics and phonotactics) and for each group (i.e., full-term [FT] high SES, full-term low SES, preterm [PT] high SES and preterm low SES) at each testing point (i.e., 7.5, 9, 10.5 and 12 months), '✓' indicates infants' ability to discriminate/prefer the contrast/list, '?' unknown, 'X' unable to discriminate/prefer the contrast/list

families. Test drop-out rates were 12% within sessions and 4% longitudinally.

2.2 | Stimulus materials

2.2.1 | Prosody: Perceptual narrowing for non-native lexical tones

Stimuli were the same as the ones used by Yeung et al. (2013). Cantonese tones were instantiated on a CV syllable, pronounced 'chee' (/tɕhi/). These speech tokens were recorded in a sound-attenuated booth from an adult female native speaker of Cantonese, who produced sentences in an adult-directed register that included the target syllable with either Tone 25 (此 'this; thus'; 始'start') or Tone 33 (次 'next'; 刺 'thorn'). Four tokens of each tone type were isolated ($M_{duration}$ = 597 ms; SD = 17) to create the stimuli and all tokens were normalized for amplitude ($M_{amplitude}$ = −15.41 dB; SD = 0.42).

2.2.2 | Phonetics: Perceptual narrowing for a non-native consonant contrast

Two Hindi phonetic contrasts:/t̪/ (i.e., voiceless unaspirated dental stop) and/t/ (i.e., voiceless unaspirated retroflex stop) instantiated on a CV syllable/t̪a/ and/ta/. The speech tokens were recorded by a female native speaker of Hindi, who produced sentences including the target syllable with either the/t̪/ contrast (ताल 'rhythm') or the/t/ contrast (टाल 'stack'). Four tokens of each tone type were isolated ($M_{duration}$ = 319 ms; SD = 14) to create the stimuli, and all tokens were normalized for amplitude ($M_{amplitude}$ = −16.41 dB; SD = 0.25).

2.2.3 | Phonotactics: Sensitivity to the frequency of phoneme sequences

Twenty-four consonant–vowel–consonant (CVC) English pseudo-words: 12 items with a higher probability (HP) of occurrence:/dʌs/,/kʌn/,/pʌm/,/sʌl/,/bis/,/dis/,/pim/,/ɹin/,/keb/,/pek/,/sed/, and/tes/; and 12 items with a lower probability (LP) of occurrence:/ʧʌʃ/,/ʧeg/,/wʌʧ/,/jʌdʒ/,/jiʃ/,/øʌv/,/øeð/,/giʃ/,/ziʧ/,/ziø/,/ʃeg/,/ʃeø/. These items were taken from Jusczyk et al. (1994). Stimuli were recorded by a female native speaker of British English. Two tokens of each item were selected ($M_{duration}$ = 657 ms; SD = 45) and used to create four lists: two lists with the 12 HP items (different tokens, the order of the items in the two lists being reversed) and two lists with the 12 LP items (same manipulation). All tokens were normalized for amplitude ($M_{amplitude}$ = −16.94 dB; SD = 2.5). The duration of all the lists was 18.00 s (M_{ISIs} = 877 ms).

2.2.4 | Apparatus and procedure

All three experiments took place in a sound-attenuated and dimly lit room. The infant sat on the parent's lap approximately 36 inches away from a 55" Samsung plasma screen. Auditory attention was measured by recording looking time towards a visual stimulus as infants were simultaneously presented with auditory tokens (see Figure 2). The parent, who was listening to music over headphones throughout the study, was instructed not to speak and not to point at the screen. A video camera was hidden under the TV screen, and an experimenter could observe the infant's eye gaze direction from a computer monitor in another room, where stimuli presentation was controlled. The sounds were presented to infants at a level of about 65 dB. The experimenter was blind to the sound presented and recorded infant looking times by pressing a button.

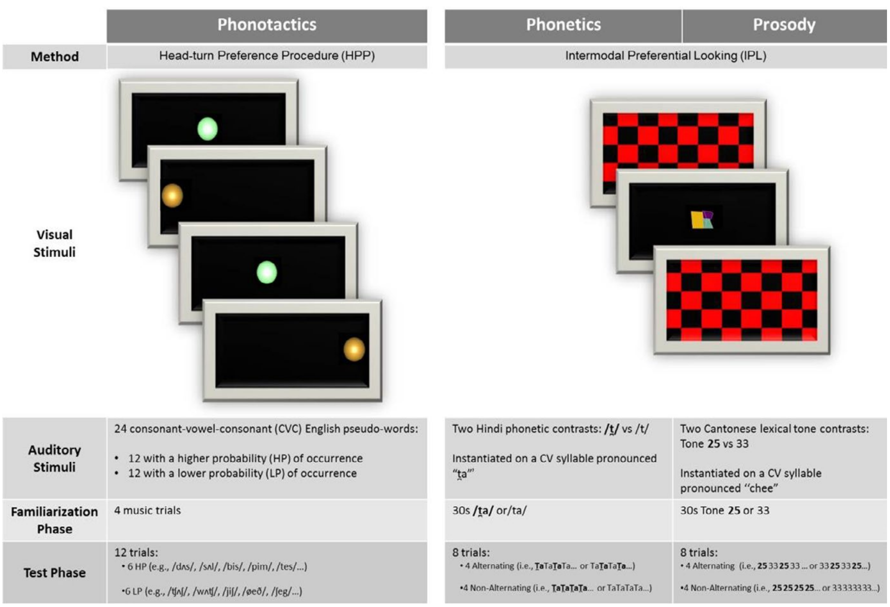

FIGURE 2 Summary of the methods used in the phonotactic (left panel), phonetic and prosody (right panel) experiments

For the prosody and phonetics experiments, a static visual stimulus (a black and red checkerboard) was presented on the screen. In all trials, the auditory and visual presentation continued until an infant looked away for 2 s, at which point the visual stimulus disappeared and an animation appeared to attract the attention of the infant. Once the infant looked again, the next trial began. Each trial had a maximum looking time of 30 s. Infants accumulated 30 s of looking time to one tone type in the familiarization phase. Two separate strings were created for this (i.e., infants heard either Tone 25 or Tone 33 for the prosody experiment and either/t̪a/ or/ta/ contrast for the phonetics experiment), and each contained a pseudo-random order of all four tokens. In a subsequent test phase of eight trials (i.e., four alternating and four non-alternating trials), discrimination was assumed if infants looked longer at 'alternating' trials (i.e., Alt trials), which contained two stimuli types, compared to either type of 'non-alternating' trials (i.e., Non-Alt trials), which contained only one type. Both Alt and Non-Alt trials each contained four tokens. Two Alt trials began with each contrast (e.g. 33–25–33–25… vs. 25–33–25–33…). Pseudo-random orders of Non-Alt trials were also created (i.e., two pseudo-random orders for each contrast). A 1-s inter-stimulus interval separated individual tokens in all trials. In the test phase, Alt and Non-Alt test trials were presented in rotating order (i.e., N-A-N-A-N-A-N-A or A-N-A-N-A-N-A-N). Each infant heard two Non-Alt trials containing each contrast, and each kind of trial was heard at least once in each half of the test phase. Across all infants, the contrast type heard during familiarization, as well as the order of each type of Alt trials were maximally counterbalanced. Trained observers who were blind to the auditory stimuli coded infant looking behaviour online using Habit 2 (Oakes, Sperka, DeBolt, & Cantrell, 2019).

For the phonotactics experiment, the TV screen was divided into three vertical regions, left, right and central, and flashing light-like animations were presented at the centre of each region. The head-turn preference procedure (HPP) was used (Jusczyk, Cutler, et al., 1993). Each trial began with a green light on the central region of the TV screen blinking until the infant had oriented to it. Then, a yellow light on one of the side regions of the TV screen began to blink. The setup that was available at the laboratory where the infants were tested is different from the classical HPP setup in that a single very wide plasma screen was used. However, we made sure that three locations on the screen appeared to the infant in such a way (i.e., infant seated close to the screen [36 inches away] and the side locations being separated from the centre by the largest distance possible) that looking to the sidelights required a head turn, just like in the traditional setup. When the infant turned in that direction, the stimulus for that trial began to play. Each stimulus was played to completion or stopped after the infant failed to maintain the gaze for 2 consecutive seconds. If the infant looked away from the target in any direction for less than 2 s and then looked back again, the trial continued, but the time spent looking away (when the experimenter released the buttons) was automatically subtracted from the orientation time by the program. Thus, the maximum looking time for a given trial was the duration of the entire speech sample. Infants' looking behaviour was coded offline using the video recording made during the experiment. Each session began with two musical trials, one presented on each side, to allow infants to practice one head-turn to each side before the actual test phase began. The test phase consisted of 16 trials divided into two blocks (in each of which the two lists of each type of stimulus were presented twice). The order of the different lists within each block was pseudo-randomized.

2.3 | Ethics

This study received ethics approval from the Health Research Authority South Central – Hampshire B Research Ethics Committee, as well as Oxford Brookes University Research Ethics Committee (UREC). All procedures performed in this manuscript were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. All participating caregivers gave informed consent. Children received a small gift at each testing time point, and caregivers were given £60 (i.e., £10 during for each of the first three visits and £30 at the end of the study).

2.4 | Results

2.4.1 | Statistical analyses

The statistical analyses were performed on looking times values. We used the R-software (R version 3.0.; package lme4, Bates, Mächler, Bolker, & Walker, 2014) to run linear mixed-effects models (Bates et al., 2014; Pinheiro & Bates, 2000). Items and participants were random-effect variables. Stimulus Type (alternating vs. non-alternating for the prosody and phonetic experiment and high probability vs. low probability for the phonotactic experiment), Socioeconomic Status (high SES vs. low SES), Term (preterm vs. full-term) and Age (7.5, 9, 10.5 and 12 m) were fixed-effects variables. We included in all the analyses the most complex adequate adjustment model (i.e., Barr, Levy, Scheepers, & Tily, 2013). Stepwise model comparisons were conducted from the most complex to the simplest model, and the one with the most complex adjustment but the smallest Bayesian information criterion (BIC; (Schwarz, 1978) and significant χ^2 test for the log-likelihood was retained. The best-fitting model across tasks was: *lmer(TotalLook ~ SES * Term * Age * StimType + (Age|SubjectID) + (1|StimName)*. For all the tests, the *p*-values refer to the *F* values on the Fisher distribution. The error degree of freedom was computed by the subtraction of the number of observations and the number of conditions (N-n-1). Finally, we used orthogonal contrasts for multiple comparisons. We only report the results that reached statistical significance.

2.4.2 | Prosody: Perceptual narrowing for non-native lexical tones

The effect of Stimulus Type was significant, $F(1, 6.00) = 16.75$, $p = .006$, such that infants had longer orientation times to alternating than to non-alternating trials ($M_{Alt} = 9.78$s, $SD = 3.88$;

$M_{Non\text{-}Alt}$ = 6.92s, *SD* = 2.71, see Figure 3). The interaction between Term and Stimulus Type was also significant, $F(1, 2{,}071.01) = 36.89$, $p \le .001$, indicating that the effect of Stimulus Type changed between the preterm and the full-term group. The interaction between Age and Stimulus Type was also significant, $F(3, 2{,}071.01) = 75.86$, $p \le .001$, indicating that the effect of Stimulus Type changed between age groups. Planned comparisons revealed that the Stimulus Type effect was significant at 7.5 months $t(75) = 4.33$, $p \le .001$, 9 months $t(75) = 3.56$, $p \le .001$, and 10.5 months, $t(75) = 3.06$, $p = .004$, but not at 12 months. More importantly, the interaction between Term, Age and Stimulus Type was also significant, indicating that the effect of Stimulus Type changed between Term groups across ages $F(3, 20.71.01) = 13.79$, $p \le .001$. Planned comparisons revealed that the Stimulus Type effect was significant for the full-term group at 7.5 months, $t(39) = 3.40$, $p \le .001$ and at 9 months $t(39) = 2.97$, $p = .005$, but it was significant at 7.5 months, $t(39) = 4.34$, $p \le .001$, 9 months $t(39) = 3.63$, $p \le .001$, and 10.5 months $t(39) = 2.79$, $p = .008$ for the preterm group.

2.4.3 | Phonetics: Perceptual narrowing for a non-native consonant contrast

The effect of Stimulus Type was significant, $F(1, 8.65) = 101.52$, $p \le .001$, such that infants had longer orientation times to alternating than to non-alternating trials (M_{Alt} = 7.61s, *SD* = 4.54; $M_{Non\text{-}Alt}$ = 6.25s, *SD* = 3.75, see Figure 4). The effect of Term was also significant, preterm babies had overall longer orientation times than full-term infants $F(1, 70.40) = 15.93$, $p \le .001$. Furthermore, the interaction between Age and Stimulus Type was significant, $F(3, 2{,}050.43) = 31.41$, $p \le .001$, indicating that the effect of Stimulus Type changed between age groups. Planned comparisons revealed that the Stimulus Type effect was significant at 7.5 months $t(75) = 12.97$, $p \le .001$, 9 months $t(75) = 12.00$, $p \le .001$, and 10.5 months, $t(75) = 4.50$, $p \le .001$ but not at 12 months. More importantly, the interaction between SES, Age and Stimulus Type was also significant, indicating that the effect of Stimulus Type changed between SES groups across ages $F(3, 2{,}051.60) = 4.30$, $p = .005$. Planned comparisons revealed that the Stimulus Type effect was significant for the High-SES group at 7.5 months, $t(39) = 8.71$, $p \le .001$ and at 9 months $t(39) = 2.45$, $p = .02$, but it was significant at 7.5 months, $t(39) = 9.52$, $p \le .001$, 9 months $t(39) = 3.05$, $p = .004$, and 10.5 months $t(39) = 2.18$, $p = .035$ for the Low-SES group.

2.4.4 | Phonotactics: Sensitivity to the frequency of phoneme sequences

The effect of Stimulus Type was significant, $F(1, 6.36) = 25.27$, $p = .002$, such that infants had longer orientation times to high-probability than to low-probability lists (M_{HP} = 8.11s, *SD* = 2.33; M_{LP} = 6.80s, *SD* = 2.11, see Figure 5). The effect of Term was also significant, preterm babies had overall longer orientation times than full-term infants $F(1, 68.95) = 13.78$, $p \le .001$. The interaction between Age and Stimulus Type was significant, $F(3, 3{,}089.52) = 30.30$, $p \le .001$, indicating that the effect of Stimulus Type changed between age groups. Planned comparisons revealed that the Stimulus Type effect was only significant at 10.5 months, $t(75) = 4.42$, $p \le .001$ and at

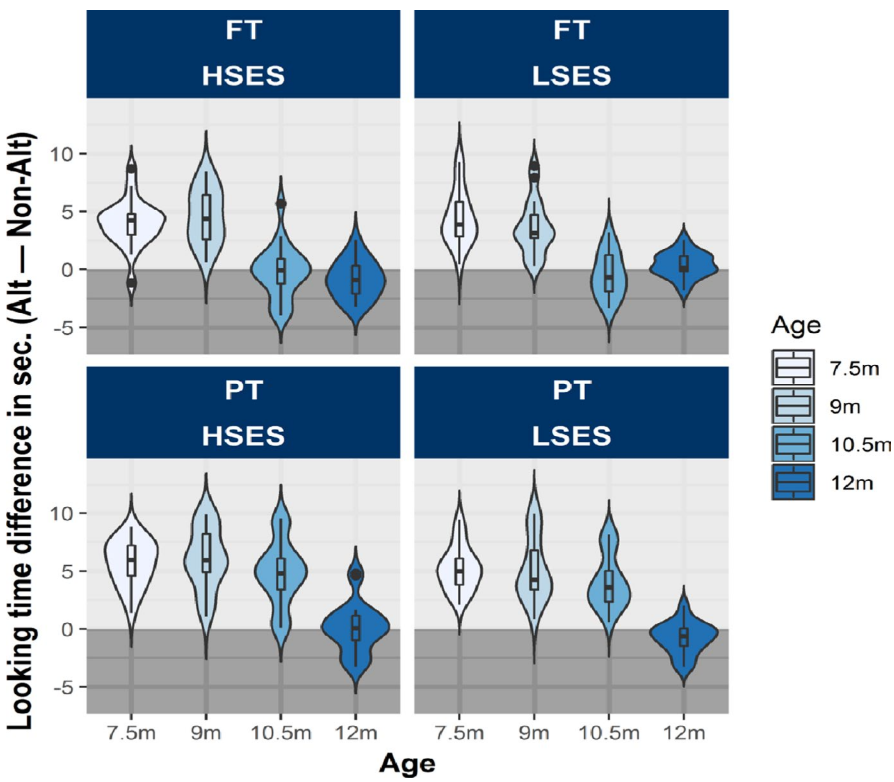

FIGURE 3 Looking time differences in the prosody experiment ($LT_{difference} = LT_{Alternating} - LT_{Non\text{-}Alternating}$) for the four different groups (i.e., preterm high SES, preterm low SES, full-term high SES and full-term low SES) presented as boxplots, indicating the median and quartiles with whiskers reaching up to 1.5 times the interquartile range. The violin plot outlines illustrate kernel probability density (i.e., the width of the shaded area represents the proportion of the data located there). Scores above zero represent a preference for alternating sequences (light grey background), whereas scores below zero represent a preference for non-alternating sequences (dark grey background)

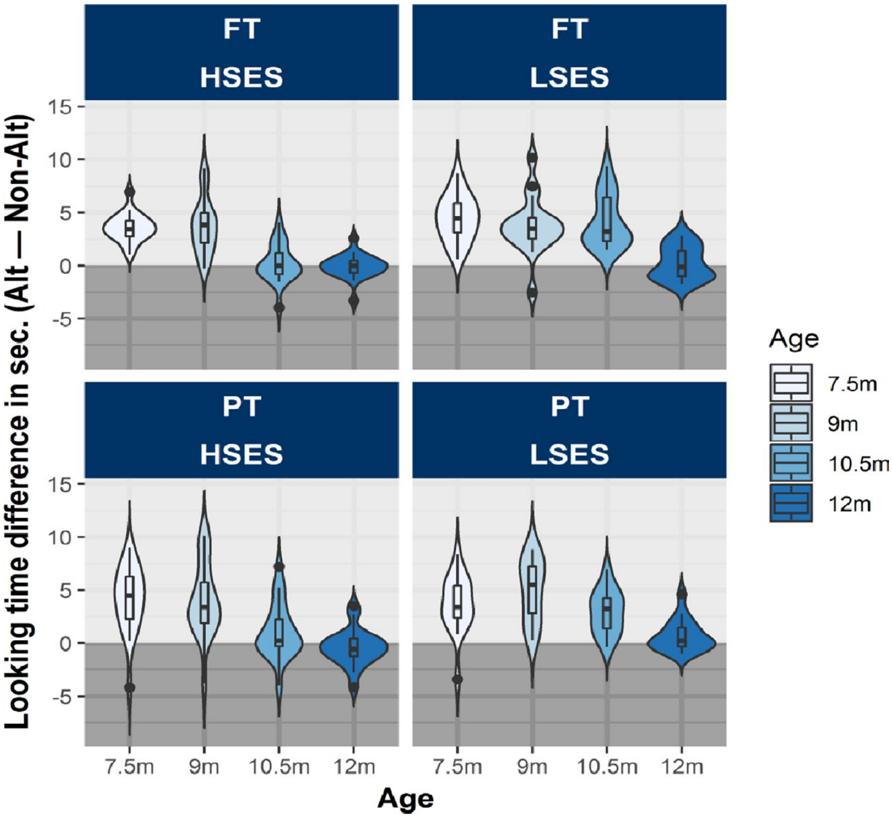

FIGURE 4 Looking time differences in the phoneme discrimination experiment ($LT_{difference} = LT_{Alternating} - LT_{Non\text{-}Alternating}$) for the four different groups (i.e., preterm high SES, preterm low SES, full-term high SES and full-term low SES) presented as boxplots, indicating the median and quartiles with whiskers reaching up to 1.5 times the interquartile range. The violin plot outlines illustrate kernel probability density (i.e., the width of the shaded area represents the proportion of the data located there). Scores above zero represent a preference for alternating sequences (light grey background), whereas scores below zero represent a preference for non-alternating sequences (dark grey background)

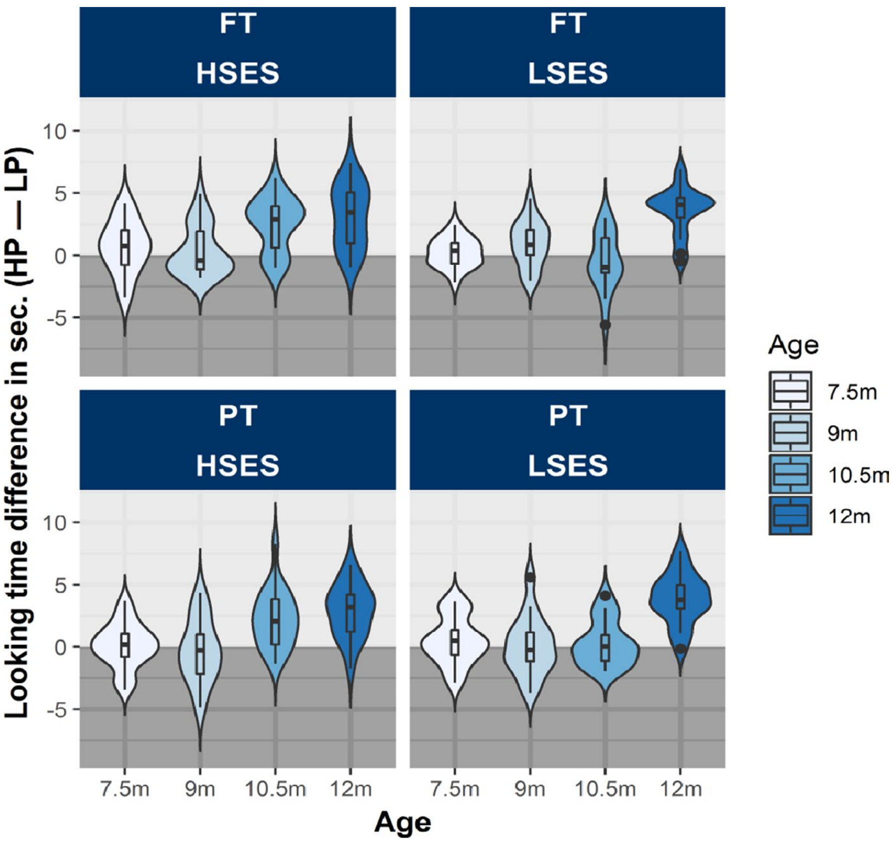

FIGURE 5 Looking time differences in the phonotactic experiment ($LT_{difference} = LT_{HP} - LT_{LP}$) for the four different groups (i.e., preterm high SES, preterm low SES, full-term high SES and full-term low SES) presented as boxplots, indicating the median and quartiles with whiskers reaching up to 1.5 times the interquartile range. The violin plot outlines illustrate kernel probability density (i.e., the width of the shaded area represents the proportion of the data located there). Scores above zero represent a preference for high-probability sequences (light grey background), whereas scores below zero represent a preference for low-probability sequences (dark grey background)

12 months $t(75) = 13.14$, $p \le .001$. More importantly, the interaction between SES, Age and Stimulus Type was also significant, indicating that the effect of Stimulus Type changed between SES groups across ages $F(3, 3{,}089.40) = 7.96$, $p \le .001$. Planned comparisons revealed that the Stimulus Type effect was significant for the High-SES group at 10.5 months, $t(39) = 6.26$, $p \le .001$ and at 12 months $t(39) = 7.21$,

$p \leq .001$, but it was only significant at 12 months for the Low-SES group only $t(35) = 8.46$, $p \leq .001$.

To summarize, the results of these experiments (c.f., Figure 6) showed a significant effect of prematurity, but no effect of socioeconomic status for prosody (i.e., suprasegmental perceptual narrowing for non-native lexical tones); but a significant effect of SES and no effect of prematurity for phonetics (i.e., segmental perceptual narrowing for a non-native consonant contrast) and phonotactics (i.e., sensitivity to the frequency of phoneme sequences).

3 | DISCUSSION

The goal of the present study was to explore early speech perception in infants born preterm or full-term and from lower- or higher-SES families. Infants' prosodic (i.e., suprasegmental perceptual narrowing for non-native lexical tones), phonetic (i.e., segmental perceptual narrowing for a non-native consonant contrast) and phonotactic (i.e., sensitivity to the frequency of phoneme sequences) development was followed longitudinally at 7.5, 9, 10.5 and 12 months of chronological age. The results for the prosody experiment established a significant effect of prematurity, but no effect of socioeconomic status. Full-term infants from lower- and higher-SES backgrounds stopped being able to discriminate Cantonese lexical tones by 10.5 months of age (see Figure 7 for a summary of the results). However, preterm infants regardless of their family's SES were still able to discriminate these tones at 10.5 months and it was not until 12 months that they were no longer able to detect the difference. The phoneme discrimination results showed a different picture: a significant effect of SES was found, but no effect of prematurity. Infants from higher-SES families at 10.5 months were no longer able to discriminate the Hindi phonetic contrast irrespective of their Term status (i.e., preterm vs. full term). Infants from lower-SES backgrounds were no longer able to discriminate this phonetic contrast at 12 months of age. The results for the phonotactic experiment were in line with the results found for phoneme discrimination, a significant effect of SES was also found without an effect of prematurity. Preterm and full-term infants from higher-SES families showed a preference for the lists having sequences with a high probability of occurrence at 10.5 months. However, this preference emerged between 10.5 and 12 months for infants from lower-SES backgrounds. Overall these results suggest that different constraints apply to the acquisition of different phonological subcomponents.

According to our results, preterm birth only had a significant effect on the acquisition of prosody, but no effect was found for phonetics or phonotactics. These results are in line with previous studies showing that preterm infants were able to distinguish their native language from another rhythmically similar language and a trochaic stress pattern from an iambic stress pattern later than their full-term peers (Bosch, 2011; Herold et al., 2008; Peña et al., 2010). Taken together, these results indicate that perceptual narrowing of non-native lexical tones, language rhythm discrimination and stress pattern discrimination all follow a different timecourse in infants born preterm compared to their full-term peers. Interestingly all three are related to suprasegmental properties of the language: tone, rhythm and stress; which suggest the existence of a more general delay for preterm infants' prosodic development (see discussion below). Furthermore, these results are also consistent with the results found by Gonzalez-Gomez and Nazzi (2012) showing no difference between the phonotactic development of preterm and full-term French-learning infants at 10 months of age. Our results indicate that infants born preterm show phonetic and phonotactic perceptual patterns that are similar to those of their full-term peers. By 10.5 months preterm and full-term infants showed a decrease in their ability to discriminate non-native contrasts and a preference for sound sequences that are frequent in their native language.

However, the phonetic results contrast with the ones found by Jansson-Verkasalo et al. (2010), showing no evidence of diminished

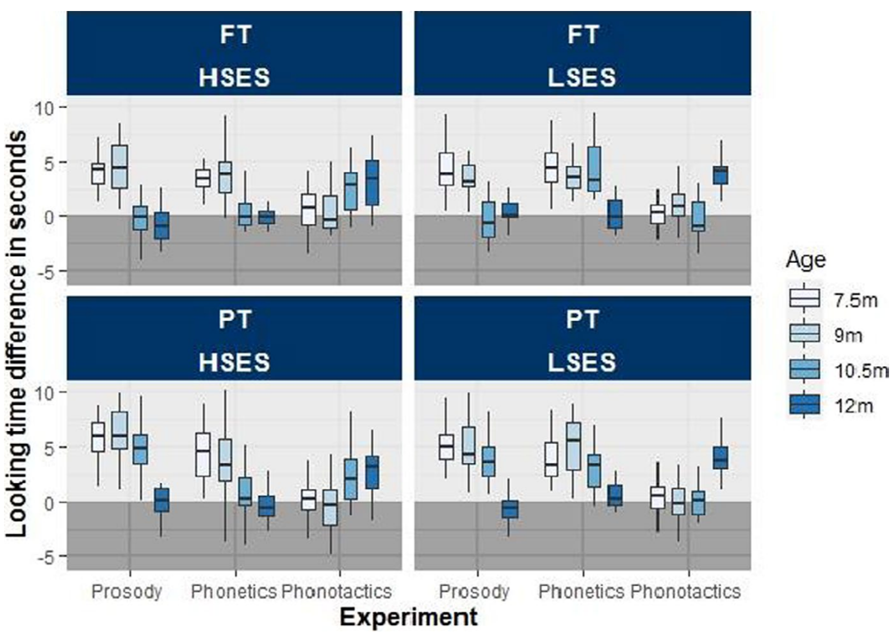

FIGURE 6 Looking time differences in all three experiments (i.e., prosody, phonetics and phonotactics) for the four different groups (i.e., preterm high SES, preterm low SES, full-term high SES, and full-term low SES) presented as boxplots, indicating the median and quartiles with whiskers reaching up to 1.5 times the interquartile range. Scores above zero represent a preference for alternating/high-probability sequences (light grey background), whereas scores below zero represent a preference for non-alternating/low-probability sequences (dark grey background)

	Prosody				Phonetics				Phonotactics			
	7.5m	9m	10.5m	12m	7.5m	9m	10.5m	12m	7.5m	9m	10.5m	12m
FT H-SES	✓	✓	x	x	✓	✓	x	x	x	x	✓	✓
FT L-SES	✓	✓	x	x	✓	✓	✓	x	x	x	x	✓
PT H-SES	✓	✓	✓	x	✓	✓	x	x	x	x	✓	✓
PT L-SES	✓	✓	✓	x	✓	✓	✓	x	x	x	x	✓

FIGURE 7 Summary of the different developmental trajectories found for each of the language subcomponents (i.e., prosody, phonetics, and phonotactics) and for each group (i.e., full-term high SES, full-term low SES, preterm high SES and preterm low SES) at each testing point (i.e., 7.5, 9, 10.5 and 12 months), '✓' indicates infants' ability to discriminate/prefer the contrast/list, 'X' unable to discriminate/prefer the contrast/list

MMN response to a non-native vocalic phoneme contrast (i.e., Estonian vowel) in preterm Finnish-learning infants at 12 months, suggesting that prematurely born infants maintain their ability to discriminate accurately non-native vocalic phonemes at the age of 1 year. Similarly, Figueras and Bosch (2010) found differences between the ability of preterm and full-term infants to discriminate native vowel contrasts at 4 but not at 8 months of age. Methodological differences might explain these dissimilar results. For example, Jansson-Verkasalo et al.'s study (2010) and the present study focused on the decline in discrimination of non-native contrasts, whereas Figueras and Bosch's (2010) study focused on the discrimination of native contrasts. Furthermore, Jansson-Verkasalo et al. (2010) presented isolated vocalic phonemes (V) whereas Figueras and Bosch (2010) used CVCV sequences, and we used consonant–vowel (CV) syllables. But more importantly, Jansson-Verkasalo et al. (2010) and Figueras and Bosch (2010) both used vocalic contrasts and we used a consonantal contrast. This is particularly relevant given that, compared to consonants, vowels are much more clearly heard in the womb (see Granier-Deferre, Bassereau, Ribeiro, Jacquet, & DeCasper, 2011 for a review). In fact, spectrograms show that F0 and the first formants of vowels are well transmitted in utero (Querleu, Renard, & Crepin, 1981; Querleu, Renard, Versyp, Paris-Delrue, & Crèpin, 1988; Querleu, Renard, Versyp, Paris-Delrue, & Crèpin, 1988). Furthermore, several studies have shown that there is greater attenuation of the higher frequencies relevant to consonant identification (Armitage, Baldwin, & Vince, 1980; Granier-Deferre, Lecanuet, Cohen, & Busnel, 1985; Griffiths, Brown, Gerhardt, Abrams, & Morris, 1994). Therefore, attunement for vowels results from speech exposure starting even before term, whereas this is not the case for consonants (see Tsuji & Cristia, 2014 for a discussion). In fact, there is evidence showing that infants can learn about the prosodic patterns of their native language prenatally. Newborns were already sensitive to the prosodic grouping (Abboub, Nazzi, & Gervain, 2016) and the vocalic segments (Moon, Lagercrantz, & Kuhl, 2013) of their native language. Taken together, these results support the existence of a *'prenatal prosodic bootstrapping'* (Gervain, 2018) resulting from a unique developmental sequence where infants first experience speech prosody alone, and only later they are exposed to the full-band speech signal. This is crucial given that infants born preterm lose a significant part of this prenatal exposure (see discussion below).

The delay found in preterm infants' development of prosody could be explained by three different hypotheses. A first possibility, proposed by Peña et al. (2010) and Herold et al. (2008), and compatible with data showing that prosodic and phonetic/phonotactic information are already processed by different neural networks in infancy (Dehaene-Lambertz, 2000), would be the existence of different developmental trajectories for prosody and phonetics/phonotactics, suggesting that neural immaturity affects different language levels in different ways. However, a second possibility would be that the time-lag found for prosody is due to differences in the amount of exposure to the input, given that prosody is already heard in utero. Thus, at 7 months of age full-term infants have had 7 months of extra-uterine exposure plus ± 7 weeks of intrauterine exposure, whereas preterm 7-month- olds have had only extra-uterine exposure. As discussed before, this might also be the case for vocalic discrimination. As consonantal phonetic information and phonotactic information are only heard after Term, both preterm and full-term infants only have extra-uterine exposure. A third plausible explanation would be that the difference observed is due to the loss of intrauterine exposure to prosody. Preterm infants, when they are born, have direct and simultaneous access to prosodic, phonetic and phonotactic information. This synchrony compared to the precedence of prosody in typical development might cause preterm infants to put less processing weight on prosody than on phonetics and phonotactics, triggering a delay in prosodic but not phonetic or phonotactic acquisition.

Interestingly, although preterm infants' phonetic and phonotactic perceptual patterns were overall similar to those of their full-term peers (i.e., both showing a preference for phonotactic sequences with high probability of occurrence and no discrimination of a non-native phonetic consonant contrast at 10.5 months of age), the results also showed significant differences between groups in terms of looking times. Preterm infants had overall longer orientation times than full-term infants in both the phonetic and phonotactic experiments. Differences in visual fixation measures between preterm and full-term infants have previously been found in the literature (Ortiz-Mantilla, Choudhury, Leevers, & Benasich, 2008; Ramon-Casas, Bosch, Iriondo, & Krauel, 2013). These measures are considered to be a reflection of processing speed (Colombo, 1993). In fact, it has been suggested that preterm infants might show longer visual fixation measures when they succeed in solving a task (Figueras & Bosch, 2010). So although infants were able to 'solve' the phonetic and phonotactic tasks, these differences might suggest that their processing speed was slower compared to their full-term peers.

Socioeconomic status was found to have a significant effect on the acquisition of phoneme discrimination and phonotactics, but no effect was found for prosody. These results show, for the first time, the effects that SES can have on early language development. More specifically, SES has been found to affect perceptual narrowing, which is considered as the first sign that infants are acquiring their native language (Tsuji & Cristia, 2014). These results are in line with findings showing that children from socioeconomically disadvantaged areas tend to have limited language skills. In fact, one study found that more than half of the 3–5-year-old children from disadvantaged backgrounds showed a language delay (Locke, Ginsborg, & Peers, 2002). Differences in vocabulary and language processing efficiency between infants from higher- and lower-SES families are already evident at 18 months: a 6-month gap between SES groups in processing skills is apparent at 24 months of age (Fernald et al., 2013). Our results suggest, for the first time, that this social gradient emerges from as early as 10 months.

Why is social disadvantage associated with poor language skills? This is not a simple question but the critical role of early home language on infants' language acquisition is undeniable (Connell & Prinz, 2002; Forget-Dubois et al., 2009; Huttenlocher, 1998; Walker, Greenwood, Hart, & Carta, 1994). Some authors have highlighted the enormous differences in the quantity of language addressed to children from different socioeconomic backgrounds in their first two and a half years of life. According to Hart and Risley (1995), by age 3 years, children from high-SES families have been exposed to 30 million more words than children from low-SES families, this became known as 'the 30 million word gap' (Hart & Risley, 2003). However, this does not seem to be only an issue of input quantity. Positive quality of parent–child interactions and increased parental verbal responsiveness are essential in shaping a child's language development (Evans & Shaw, 2008; Harris, Jones, Brookes, & Grant, 1986; Harris, Jones, & Grant, 1984; Neuman, Koh, & Dwyer, 2008; Vigil, Hodges, & Klee, 2005). An increasing amount of evidence has shown that caregiver education is positively correlated with the quantity of infant-directed speech and the quality of parental responses to their infant's attention, gestures and vocalizations (Bornstein, Haynes, & Painter, 1998; Hoff, 2003a, 2003b; Hoff-Ginsberg, 1991; McGillion et al., 2013; Mundy et al., 2007). Differences in responsiveness are thought to be crucial to explain variance in early lexical development, given that, at this stage, learning is more likely to occur if the caregiver talks about what is in the focus of the infant's attention (Hoff, 2003a; McGillion et al., 2013; McGillion, Pine, Herbert, & Matthews, 2017). Furthermore, the differences in language and interaction experiences have been found to have lasting effects on a child's performance later in life. These differences in the amount and quality of the input and parental responsiveness might explain the delay found for phonetic and phonotactic development in infants from lower-SES backgrounds.

While our results conclusively show that prematurity and SES have different effects on each phonological subcomponent, several questions remain unanswered. For example, what are the mechanisms behind these delays? Are they due to differences in the amount of the input/exposure to the input? Are they caused by differences in the quality of parental interactions? Are these parts of a more general cognitive delay or due to differences in speed processing? Further research is also needed to investigate the contrasting results found in previous studies on vowel discrimination (Figueras & Bosch, 2010; Jansson-Verkasalo et al., 2010) and our results on consonantal discrimination to determine whether preterm infants particularly struggle with vowels. The present study focused on the decline in discrimination of a non-native contrast, not on the increase in the capacity to discriminate native contrasts. Future studies need to investigate the latter in order to get a better understanding of the effect of preterm birth and SES on the acquisition of native phonological components. Importantly, the link between early speech perception and later lexical acquisition deserves to be explored. Finally, future research should also consider the role that other factors, such as genetics, play in the development of these delays. This is particularly important given the evidence that some genetic risk factors take on a particularly important role in specific environmental settings—the so-called 'differential susceptibility' model. For example, in high-SES families, genetic differences have been found to account for ≈60% of the variance in IQ, whereas environmental differences were almost non-existent. For low-SES families, the pattern was reversed (Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003).

At this point, it is important to highlight the fundamental role that early speech perception plays on the acquisition of later linguistic skills. Infants have been shown to use their knowledge about the phonological regularities of their language to segment (e.g., Gonzalez-Gomez & Nazzi, 2013; Kooijman, Hagoort, & Cutler, 2009; Mattys & Jusczyk, 2001; Polka & Sundara, 2012), and learn new words (Gonzalez-Gomez, Poltrock, & Nazzi, 2013; Graf Estes, Edwards, & Saffran, 2011). Furthermore, this transition into language-specific perceptual abilities has been shown to have predictive value for later language growth in the second year of life, specifically vocabulary comprehension and production and basic grammatical knowledge. Accordingly, the discrimination of a native vocalic contrast at 6 months of age significantly correlated with word comprehension, word production and phrase understanding measured at 13, 16 and 24 months (Tsao, Liu, & Kuhl, 2004). A negative correlation between native (i.e., stop consonants) and non-native (i.e., fricative Mandarin consonants) phonetic discrimination was also found (Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005). Interestingly, the 'preserved' capacity to differentiate a non-native contrast was negatively correlated with expressive vocabulary measures at 18 and 24 months of age, and sentence complexity at the latter age. Typically developing children perceptual narrowing involves an increase in their ability to discriminate native contrasts and a decrease in their sensitivity to non-native contrasts. The absence of this pattern at 10.5 months may suggest that this process is either delayed or follows an atypical trajectory. In both cases, the less typical pattern might suggest that these infants are not learning effectively from the input and, as a result, they might also be progressing more slowly towards later language skills, such as lexical growth and morphosyntactic development.

Taken together, our results suggest that the timecourse of early language development in preterm infants and those from lower-SES backgrounds differ from that found in full-term infants from higher-SES backgrounds. Given theories stipulating that the typical brain has a particular developmental timing and that when some subcomponents do not develop in the typical period or at the typical speed, there will be cascading effects (e.g., Karmiloff-Smith, 1997), the pattern of early development that emerges could trigger later language deficits in the school years.

Our study also highlights the importance of conducting longitudinal studies to better understand how later language problems unfold. It is only by following these populations at risk longitudinally that we will be able to track patterns of language development over time including continuities, discontinuities and transition points. We will only then be able to develop and test models of causal relationships between early events or characteristics and later outcomes (Farrington, 1991; Rutter, 1994).

To conclude, the results of the present study suggest that neural immaturity and socioeconomic status indicators (i.e., income, education and occupation) do not affect the acquisition of all language subcomponents in the same way. These findings indicate the possibility that different constraints apply to the acquisition of different phonological subcomponents. The results also suggest that language problems related to prematurity and socioeconomic disadvantage may partially originate already from this early tuning stage of language acquisition. Lastly, they highlight the importance of conducting further longitudinal studies focused on early language acquisition to specify the subdomains that might be affected, to better understand the development of these populations at risk.

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ENDNOTE

[1] Please note that similar native language discrimination abilities have been found as early as 3.5 months in full-term infants (e.g., Bosch & Sebastián-Gallés, 1997; Molnar et al., 2014).

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