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## PAPER

# Call me Alix, not Elix: vowels are more important than consonants in own-name recognition at 5 months

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### Abstract

*Consonants and vowels differ acoustically and articulatorily, but also functionally: Consonants are more relevant for lexical processing, and vowels for prosodic/syntactic processing. These functional biases could be powerful bootstrapping mechanisms for learning language, but their developmental origin remains unclear. The relative importance of consonants and vowels at the onset of lexical acquisition was assessed in French-learning 5-month-olds by testing sensitivity to minimal phonetic changes in their own name. Infants' reactions to mispronunciations revealed sensitivity to vowel but not consonant changes. Vowels were also more salient (on duration and intensity) but less distinct (on spectrally based measures) than consonants. Lastly, vowel (but not consonant) mispronunciation detection was modulated by acoustic factors, in particular spectrally based distance. These results establish that consonant changes do not affect lexical recognition at 5 months, while vowel changes do; the consonant bias observed later in development does not emerge until after 5 months through additional language exposure.*

### Research highlights

- Consonants are more important in distinguishing words in the lexicon and are accordingly used preferentially by toddlers and adults in word processing.
- Using HPP and a controlled design, we measured French-learning 5-month-old infants' preferences for their correctly pronounced over a minimally mispronounced version of their own name, one of the first familiar words. Behavioral results indicated sensitivity to vowel changes, and not to consonant changes.
- Moreover, detailed acoustic analyses linked individual performance to spectrally based distance only for vowels.
- This shows that 5-month-old infants do not yet attribute a privileged role to consonants when recognizing their name, thus highlighting how the complex links between speech processing and lexical acquisition in the first months of life will necessarily change with phonological and lexical development to allow the acquisition of the biases found in toddlerhood/adulthood.

### Introduction

Consonants and vowels are the two basic sound categories central to the structure of speech in all languages (Ladefoged, 1993). They differ in many respects: For example, vowels tend to be longer and louder than consonants (Repp, 1984), and are thus perceived more clearly in utero (Granier-Deferre, Ribeiro, Jacquet & Bassereau, 2011) and at birth (Bertoncini, Bijeljac-Babic, Jusczyk & Kennedy, 1988; Benavides-Varela, Hochmann, Macagno, Nespor & Mehler, 2012). Vowels are also less numerous than consonants in most languages (Maddieson, 1984). Furthermore, consonants are

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processed more categorically than vowels (Fry, Abramson, Eimas & Liberman, 1962), and by partly different brain areas as shown by neuropsychological (Caramazza, Chialant, Capasso & Miceli, 2000) and electrophysiological/brain imaging studies (Carreiras & Price, 2008). During development, native vowel categories are learned earlier (6 months: Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992) than consonant categories (10–12 months; Werker & Tees, 1984).

These differences between consonants and vowels have led to the proposal of a 'division of labor' that could help infants learn their native language (Nespor, Peña & Mehler, 2003). Specifically, two complementary functional biases have been proposed, such that '…consonants, rather than vowels, are most relevant to build the lexicon, and vowels, rather than consonants, are most relevant for grammatical [and prosodic] information' (p. 224). This hypothesis has been extremely influential in the field (see below), but very few studies have explored the origins of these hypothesized learning biases. Here we explore the respective role of consonants and vowels in the earliest steps of lexical acquisition, focusing on the emergence of the consonant bias for lexical processing.

Two kinds of hypotheses regarding the origin of the consonant bias have been offered. The 'initial bias' hypothesis states that infants start processing consonants and vowels as distinctive linguistic categories from birth, ascribing a limited role to input characteristics and thus predicting no developmental or cross-linguistic differences (Nespor *et al.*, 2003; Bonatti, Peña, Nespor & Mehler, 2007; Pons & Toro, 2010). Alternatively, 'learned bias' hypotheses propose that this bias emerges during development, as a result of infants' acquisition of the acoustic-phonetic (Floccia, Nazzi, Delle Luche, Poltrock & Goslin, 2014) or lexical (Keidel, Jenison, Kluender & Seidenberg, 2007) properties of their native language.

Many adult studies, using various tasks, have shown that consonants are privileged over vowels in lexical processing in French, Spanish, Italian, English, and Dutch. This was found in tasks measuring lexical access in both auditory (Cutler, Sebastián-Gallés, Soler-Vilageliu & Van Ooijen, 2000; Delle Luche, Poltrock, Goslin, New, Floccia & Nazzi, 2014) and written modalities (Acha & Perea, 2010; New, Araùjo & Nazzi, 2008), detection of word–forms from continuous speech (Toro, Nespor, Mehler & Bonatti, 2008), and novel word learning (Havy, Serres & Nazzi, 2014).

Several studies also tested the consonant bias in toddlers and children. These studies, initially conducted in French, revealed a consonant bias in novel word learning between 16 months and 5 years of age (Nazzi, 2005; Havy, Bertoncini & Nazzi, 2011; Havy & Nazzi, 2009; Havy *et al.*, 2014), and a consonant bias in familiar word recognition at 14 months (Zesiger & Jöhr, 2011). These findings establish that the consonant bias in (French) lexical processing is consistently present from early in development, and converging evidence has been found at 12 months in Italian-learning infants (Hochmann, Benavides-Varela, Nespor & Mehler, 2011). However, studies on English-learning infants offer a different picture. A consonant bias was found in word learning tasks at 30 months but not 16 and 23 months (Floccia *et al.*, 2014; Nazzi, Floccia, Moquet & Butler, 2009) and in word recognition tasks at 15 months but not 12, 18 or 24 months (Mani & Plunkett, 2007, 2010). These latter findings appear to go against the initial bias hypothesis, which predicts an early and language-independent consonant bias. However, it remains possible that the consonant bias would only be momentarily masked in English-learning toddlers.

Therefore, the current study aimed to specify its origin and early trajectory by testing whether the consonant bias is present from the very beginning of lexical acquisition, by 5 months of age. This age was chosen given data establishing recognition of some familiar word forms (Mandel, Jusczyk & Pisoni, 1995; Bortfeld, Morgan, Golinkoff & Rathbun, 2005; Mersad & Nazzi, 2012) and comprehension of some words (Tincoff & Jusczyk, 1999, 2012; Bergelson & Swingley, 2012) at 5–6 months. Moreover, while some of these earlier studies had examined the effects of mispronunciations on early recognition of familiar words (consonant mispronunciation in English: Bortfeld *et al.*, 2005; vowel mispronunciation in French: Mersad & Nazzi, 2012), none had directly compared the effects of consonant and vowel mispronunciations. Here, we tested whether recognition of their own names by French-learning 5-month-olds is affected by a consonant change or a vowel change. Lastly, we also conducted acoustic analyses on the stimuli used in order to determine whether infants' performance is related to acoustic properties of the stimuli presented, in order to evaluate the acoustic/phonetic learning hypothesis (Floccia *et al.*, 2014).

## Methods

Following Mandel *et al.* (1995), we used the Headturn Preference Procedure (HPP) to test the sensitivity of French-learning 5-month-olds to a consonant change (Consonant change condition) versus a vowel change (Vowel change condition) in their own name. Infants in the test groups were presented with repetitions of their own correctly pronounced name (CPs) on half of the trials, and repetitions of their own mispronounced name (MPs) on the other half of the trials. We only used one-feature phonetic changes (Consonant change condition: place, voicing or manner; Vowel change condition: place, roundedness or height). Since all phonetic changes were native French contrasts (Dell, 1985), most, if not all, contrasts were expected to be distinguishable by our French-learning participants, given evidence that most native contrasts can be discriminated by infants from birth (for reviews, see Werker, 1994; Kuhl, Conboy, Coffey-Corina, Padden, Rivera-Gaxiola & Nelson, 2008). Importantly, the use of infants' own names allowed us to test many different consonant and vowel changes (25 in the Consonant change condition and 28 in the Vowel change condition, due to some infants having the same names), providing generalizable results. A preference for CPs over MPs (indicated by the difference in looking times towards CPs and MPs, referred to as *LT.diff* later on) would indicate sensitivity to the mispronunciation (e.g. in the Consonant change condition, a baby named *Victor* should prefer listening to *Victor* over *Zictor*). As a precaution, to rule out effects due to pure acoustic preferences, yoked control infants were tested on the same stimuli as test infants with the main constraints that they had a different name, did not know anyone with the critical name, and had a name starting with the same phoneme category (consonant or vowel) as the critical name (e.g. a baby named *Martin* was presented with *Victor* vs. *Zictor*). In this way, CPs and MPs were equally unfamiliar to control infants, and no preference should be observed for CPs over MPs (i.e. a baby named *Martin* should not prefer *Victor* over *Zictor*).

According to the initial bias hypothesis (Nespor *et al.*, 2003), 5-month-olds should already be more sensitive to a consonant change than to a vowel change in their own name. Therefore, test infants should exhibit a larger preference for CPs over MPs in the Consonant change condition compared to the Vowel change condition, and no preference should be found in the yoked control groups of both experiments. Alternatively, if this prediction were not confirmed, it would suggest that the functional specialization of consonants and vowels still has to be learned at 5 months, as proposed by the 'learned bias' hypotheses. In this case, a possible outcome could be that 5-month-olds perceive and process consonant and vowel changes similarly in words, in which case we could predict a preference for their correctly pronounced names over their mispronunciations in both conditions. A further possibility is that 5-month-olds' reaction to the mispronunciations is based on the acoustic distance between the correctly versus mispronounced stimuli, independently (or not) of their consonant/vowel status. Therefore, in order to assess the contribution of the acoustic–phonetic properties of our stimuli to infants' preference responses, the consonant and vowel contrasts were characterized along three acoustic dimensions: duration, intensity and MFCCs (Mel-Frequency-Cepstrum Coefficients, a spectrally based measure of phonetically relevant acoustic information normalized for duration and intensity). These measures were used to evaluate the saliency and the discriminability of the different phonemes, and relate them to individual preference responses. We expected consonants to be overall less salient than vowels (Repp, 1984) but more discriminable as they are usually perceived more categorically than vowels (Fry *et al.*, 1962).

### Participants

All 120 participants were healthy French-learning monolingual 5-month-old infants (Table 1). For the test conditions, only infants without nicknames and who were frequently called by their own name were included. Infants in the control conditions were chosen so that they would not know anyone in their environment with the name used in the experiment. Children with names starting with a consonant were assigned to the Consonant change control group and those with names starting with a vowel to the Vowel change control group. Forty-seven additional infants were tested and their data excluded due to fussiness (36), having two consecutive trials with insufficient looking times, having more than three such trials overall (6), experimenter error (1), or being an outlier (*LT.Diff* above or below 2 *SDs* of the group Mean; 4).

### Stimuli

Each of the 60 test infants heard repetitions of a pair of stimuli corresponding to their CP (Correctly

**Table 1** *Participant information, illustration of the four experimental conditions, and examples of stimuli*

| Groups (all $n = 30$) | Stimuli (example) | Infant's name (example) | Age in days (*SD*) | # girls/ boys |
|---|---|---|---|---|
| Consonant change condition | | | | |
| Test | e.g. Victor vs. Zictor | Victor | 164 (8) | 14/16 |
| Control | e.g. Victor vs. Zictor | Martin | 164 (9) | 11/19 |
| Vowel change condition | | | | |
| Test | e.g. Esther vs. Isther | Esther | 164 (8) | 17/13 |
| Control | e.g. Esther vs. Isther | Adrien | 165 (8) | 14/16 |

pronounced) and MP (Mispronounced) names. Due to a few infants having the same names, there was a total of 28 pairs in the Consonant change condition and 25 pairs in the Vowel change condition. The same stimuli were used with the 60 yoked control infants. The MP of the names always consisted of a one-feature change (Table 2). As mentioned earlier, all changes were native French minimal contrasts according to Dell (1985), and were expected to be discriminable by French-learning infants irrespective of their age. Based on Mandel *et al.* (1995) and the fact that three different phonetic features were tested in each condition, the sample size was 30 infants in each test group. In the Consonant change condition, 10 infants were tested on a place-of-articulation change, 10 on a voicing change, and 10 on a manner-of-articulation change. In the Vowel change condition, 10 infants were tested on a place change, 10 on a roundedness change, and 10 on a height change.

For all infants, the same female native French speaker recorded 15 tokens each of CP and MP names. For both CPs and MPs, two files including the 15 tokens were made, the second file presenting the same tokens in reversed order. All sound files lasted 24 seconds.

## *Procedure*

### Behavioral experiment

Each infant was tested individually. The experiment was conducted inside a sound attenuated room, and in a booth made of pegboard panels (bottom) and a white curtain (top). The test booth had a red light and a loudspeaker (SONY xs-F1722) mounted at eye level on each of the side panels and a green light mounted on the center panel. Below the center light was a video camera used to monitor infants' behavior.

A PC computer terminal (Dell OptiPlex), a TV screen connected to the camera, and a response box were located outside the sound attenuated room. The response box, connected to the computer, was equipped with a series of buttons. The observer, who looked at the video of the infant on the TV screen to monitor the infant's looking behavior, pressed the buttons of the response box according to the direction the infant's head, thus starting and stopping the flashing of the lights and the presentation of the sounds (see below). The observer and the infant's caregiver wore earplugs and listened to masking music over tight-fitting closed headphones, which prevented either from hearing the stimuli presented. Information about the duration of the head-turn, calculated from the observer's button-pressing, was recorded by the computer.

We used the same version of the Head-turn Preference Procedure (HPP) as Mandel *et al.* (1995). Each infant was held on a caregiver's lap in the center of the booth. Each trial began with the green light on the center panel blinking until the infant oriented to it. Then, the red light on one of the side panels began to flash. When the infant turned their head in that direction, the stimulus for that trial began to play. The stimuli were delivered by the loudspeakers via an audio amplifier (Marantz PM4000). Each stimulus was played to completion or stopped immediately after the infant failed to maintain the head-turn for 2 consecutive seconds. If the infant turned away from the target by 30° in any direction for less than 2 s and then turned back again, the trial continued but the time spent looking away (when the experimenter released the buttons of the response box) was automatically subtracted from the listening time by the computer program. Thus, the maximum listening time for a given trial was the duration of the entire speech sample. If a trial lasted less than 1.5 s (insufficient looking time), the trial was repeated and the original listening time was discarded.

Each session began with two musical trials (excerpts of classical music), one on each side to give infants an opportunity to practice one head-turn to each side. The test phase consisted of eight trials divided into two blocks, in each of which the two lists of each name were presented. Order of the different lists within each block was randomized.

### Acoustic analyses of the stimuli

Three acoustic dimensions were measured to characterize the contrasted phonemes of CPs and MPs: duration, intensity and Mel Frequency Cepstral Coefficients as a measure of spectral distance (MFCCs; see below for more explanation).

For each CP/MP pair, duration and intensity were measured for the 15 tokens of the contrasted phonemes using PRAAT. This was first used to calculate mean duration and mean intensity values of the contrasted phonemes, in order to compare the relative salience and discriminability of the contrasted consonants and vowels. Second, we computed normalized duration and intensity differences (*Diff.duration*: duration difference between the contrasted phonemes of CPs and MPs divided by their mean; same for *Diff.intensity*), in order to test their link with individual performance.

MFCCs are spectrum-based features resulting from a deconvolution of the speech source (e.g. vocal fold

**Table 2** *Details of stimuli presented in the Consonant change condition (upper-panel) and the Vowel change condition (lower-panel), broken down by phonetic features (in columns): for each test infant, the correctly pronounced name (CP, corresponding to the test infant's name), the mispronunciation (MP), the phonetic feature contrasting the CP and MP (in International Phonetic Alphabet), and the control infant's name tested on this CP/MP pair are given*

Consonant change condition

| Place changes | | | | | Voicing changes | | | | | Manner changes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name | # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name | # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name |
| 1 | Sophie | chophie | s/ʃ | Martin | 1 | Judith | chudith | ʒ/ʃ | Clément | 1 | Marie | barie | m/b | Félix |
| 2 | Rémi | lémi | R/l | Micha | 2 | Pénélope | bénélope | p/b | Martin | 2 | Marie | barie | m/b | Loic |
| 3 | Gaspard | daspard | g/d | Maya | 3 | Côme | gôme | k/g | Solène | 3 | Lily | zily | l/z | Gaspard |
| 4 | Camille | tamille | k/t | Serge | 4 | Véra | féra | v/f | Toto | 4 | Lucien | ducien | l/d | Marc-Antoine |
| 5 | Marin | narin | m/n | Rose | 5 | Jules | chules | ʒ/ʃ | Loulou | 5 | Nora | zora | n/z | Botho |
| 6 | Pauline | tauline | p/t | Robinson | 6 | Pierre | bierre | p/b | Nina | 6 | Bérénice | mérénice | b/m | Diane |
| 7 | Victor | zictor | v/z | Mathieu | 7 | Corentin | gorentin | k/g | Maeli | 7 | Téa | séa | t/s | Marguerite |
| 8 | Loulou | roulou | l/R | Basil | 8 | Violette | fiolette | v/f | Mathilde | 8 | Laomé | zaomé | l/z | Mathias |
| 9 | Félix | sélix | f/s | Martin | 9 | Félix | vélix | f/v | Mara | 9 | Nouchai | zouchai | n/z | Célian |
| 10 | Félix | sélix | f/s | Paulin | 10 | Charles | jarles | ʃ/ʒ | Mona | 10 | Sanjay | tanjay | s/t | Margot |

Vowel change condition

| Place changes | | | | | Roundedness changes | | | | | Height changes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name | # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name | # | CP & Test infant's name | MP | contrast CP/MP | Control infant's name |
| 1 | Olivia | eulivia | o/ø | Ewan | 1 | Ellen | eullen | e/ø | Haythem | 1 | Alba | elba | a/ɛ | Ombelle |
| 2 | Auriane | euriane | o/ø | Anaïs | 2 | Elisa | eulisa | e/ø | Alice | 2 | Océane | ouceane | o/u | Anjali |
| 3 | Augustine | eugustine | o/ø | Alexandre | 3 | Iris | uris | i/y | Hédi | 3 | Alexandre | elexandre | a/ɛ | Héloise |
| 4 | Oriane | euriane | o/ø | Eloise | 4 | Eliott | euliott | e/ø | Andrée | 4 | Anais | enais | a/ɛ | Elio |
| 5 | Ulysse | oulysse | y/u | Hector | 5 | Ihsane | uhsane | i/y | Emmanuel | 5 | Arsène | ersene | a/ɛ | William |
| 6 | Hugo | ougo | y/u | Héloise | 6 | Elise | eulise | e/ø | Alexia | 6 | Honorine | ounorine | o/u | Ambroise |
| 7 | Augustine | eugustine | o/ø | Adèle | 7 | Erwan | eurwan | ɛ/œ | Abigaëlle | 7 | Esther | isther | e/i | Adrien |
| 8 | Hugo | ougo | y/u | Alix | 8 | Eliott | euliott | e/ø | Alexandre | 8 | Inès | enes | i/e | Adrien |
| 9 | Hugo | ougo | y/u | Aron | 9 | Eli | euli | e/ø | Aliénor | 9 | Alix | elix | a/ɛ | Ethan |
| 10 | Eugénie | ogenie | ø/o | Alienor | 10 | Elias | eulias | e/ø | Enzo | 10 | Arthur | erthur | a/ɛ | Evan |

vibrations) and speech filter (vocal tract). MFCCs were chosen rather than pitch measures because, first, pitch measures cannot be calculated for some of the consonants used in our study (unvoiced consonants). Second, MFCCs are widely used both for automatic speech and speaker recognition, as they provide a general measure of distance between two speech sounds normalized for duration and intensity that specifies well both consonantal and vocalic information (however, MFCCs do not provide information regarding saliency, contrary to duration, intensity and pitch). They have been preferentially used in word and phoneme recognition studies because they retain phonetically relevant acoustic information (e.g. Davis & Mermelstein, 1980). They involve a pre-processing of the spectral envelope of the signal with frequency bands equally spaced on the Mel scale that approximates the psychoacoustic properties of the cochlea, thus providing a better acoustic/phonetic coding than more simple measures such as spectral distance and LFCC coefficients (Linear-Frequency Cepstral Coefficients).

MFCCs were calculated using 30 ms analysis windows at a 15 ms frame rate. To do so, for each CP/MP pair, the word-initial (contrasted) phoneme of the first of the 15 tokens of each word was manually segmented using Transcriber (Barras, Geoffroy, Wu & Libberman, 2001). Then, manual segmentation was used to automatically locate the initial phonemes of the 14 other tokens using dynamic time warping (DTW; Sakoe & Chiba, 1978). DTW is a speech comparison method that automatically determines the optimal temporal matching between two speech patterns (detect segment similarities) independently of duration and speech rate. Then, MFCCs were computed using the 24 triangular filters mel-frequency spaced, a standard discrete cosine's transform and frequency bandwidth of 0–8 kHz. The subset of MFCCs employed in the classification to measure MFCC distances included 12 coefficients, c1 to c12, in order to best represent the envelope of the mel-spectrum. Note that coefficient c0 was not taken into account to exclude intensity differences that would affect MFCC distance measurements. MFCC distances correspond to the Euclidian distance between two tokens calculated for the 12 coefficients (i.e. the square root of the summed squared differences between the two MFCC sets). Finally, we tested the link between individual performance and the normalized MFCC distance between CPs and MPs (*Diff.spectral*), defined for each CP/MP pair as the ratio of the mean cross-category distance between the 15 CPs and the 15 MPs (*Dcross*) of the given pair and the mean internal variability within the 15 CPs (*DwithinCP*) and within the 15 MPs (*DwithinMP*):

$$Diff.spectral(CP,MP) = \frac{Dcross(CP,MP)}{\sqrt{\frac{1}{2}(DwithinCP^2+DwithinMP^2)}}$$

## Results

### *Behavioral results*

#### Overall analysis

Mean listening times (LTs) to the CP and MP names were calculated for each infant. Group averages are presented in Figure 1. A three-way ANOVA was conducted on LTs with a within-subjects factor of pronunciation (CP vs. MP) and between-subjects factors of group (test vs. control) and condition (Consonant change vs. Vowel change). Neither the effect of condition ($F(1, 116) = .26$, $p = .61$), group ($F(1, 116) = .87$; $p = .35$), nor the condition × pronunciation interaction ($F(1, 116) = .11$, $p = .74$) reached significance. The effect of pronunciation was only marginal ($F(1, 116) = 3.53$; $p = .06$), Importantly though, both the pronunciation × group interaction ($F(1, 116) = 7.23$; $p = .008$, $\eta^2_p = .06$) and the three-way interaction between pronunciation × group × condition ($F(1, 116) = 8.64$; $p = .004$, $\eta^2_p = .07$) reached significance, establishing that infants were not behaving in the same way in both conditions. In order to understand how consonant and vowels MPs were differently processed, separate analyses were conducted for each condition.

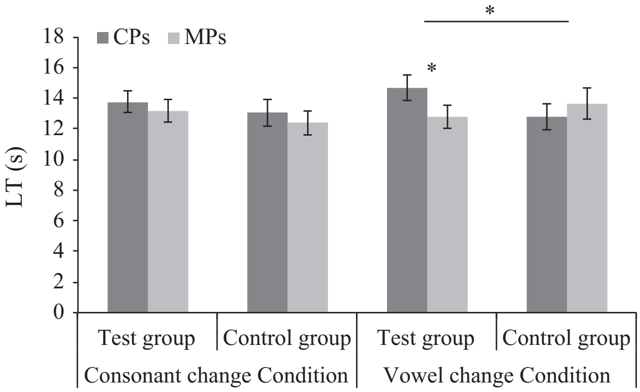


**Figure 1** *Mean listening times (and SEs) to the CP and MP names in test and control infants. Left panel: Consonant change condition; Right panel: Vowel change condition.* * indicate significant effects (p < .05).

### Consonant change condition

For the test group, the LT means were $M_{CP} = 13.87$ s ($SD = 3.91$ s) and $M_{MP} = 13.36$ s ($SD = 3.98$ s), the estimate of *LT.diff* was *Mtest* = .51 s (95% *CI* = [−.40, 1.42]) and Cohen's *d* = .21 (Cohen's *ds* are calculated with the difference of means as numerator and the standard deviation of the paired differences as denominator). For the control group, the LT means were $M_{CP} = 13.03$ s ($SD = 4.74$ s) and $M_{MP} = 12.40$s ($SD = 4.38$ s), the estimate of *LT.diff* was *Mctrl* = .64 s (95% *CI* = [−.51, 1.78]) and Cohen's *d* = .21. The size of the difference between *LT.diffs* in test and control infants was −.13 (95% *CI* = [−1.63, 1.37]) with Cohen's *d* = −.03. A two-way ANOVA on LTs with the factors of pronunciation (CP vs. MP) and group (test vs. control) was conducted. The effects of pronunciation ($F(1, 58) = 2.56$, $p = .11$), group ($F(1, 58) = .75$, $p = .39$), and the pronunciation × group interaction ($F(1, 58) = .03$, $p = .86$) all failed to reach significance. Longer LTs for CPs over MPs were found for 14 of the 30 test infants (binomial test, $p = .43$), and for 16 of the 30 control infants (binomial test, $p = .43$). This pattern of results shows no effect in either the test or control groups, and no difference between the two groups.

Moreover, a second ANOVA including the between-subjects factor of feature (place, voicing or manner; all $n = 10$) in addition to the previous factors yielded no effect of feature ($F(2, 54) = 1.16$; $p = .32$), and no interactions involving feature (all *F*s < 1). Overall, these results show that French-learning 5-month-olds are not particularly sensitive to a consonant mispronunciation in their own name, independently of the phonetic feature contrasted.

### Vowel change condition

For the test group, the LT means were $M_{CP} = 14.75$ s ($SD = 4.72$ s) and $M_{MP} = 12.89$ s ($SD = 4.35$ s), the estimate of *LT.diff* was *Mtest* = 1.86 s (95% *CI* = [.74, 2.89]) and Cohen's *d* = .62. For the control group, the LT means were $M_{CP} = 12.76$ s ($SD = 4.24$ s) and $M_{MP} = 13.82$ s ($SD = 5.02$ s), the estimate of *LT.diff* was *Mctrl* = −1.06 s (95% *CI* = [−2.10, −.01]) and Cohen's *d* = −.38. The size of the difference between *LT.diffs* in test and control infants was 2.92 (95% *CI* = [1.33, 4.51]) with Cohen's *d* = .68. A two-way ANOVA on LTs with the factors of pronunciation and group was conducted. The effect of pronunciation ($F(1, 58) = 1.14$, $p = .29$) and group ($F(1, 58) = .22$, $p = .64$) failed to reach significance, but the pronunciation × group interaction did ($F(1, 58) = 15.11$, $p = .0003$, $\eta^2_p = .21$). Planned comparisons revealed that Test infants significantly preferred their CP names compared to their MP versions ($F(1, 58) = 12.28$, $p = .0009$, $\eta^2_p = .17$) whereas Control infants marginally preferred MPs over CPs ($F(1, 58) = 3.97$, $p = .051$, $\eta^2_p = .06$). Note that this marginal (reversed) preference for vocalic MPs in Control infants, which goes against the Test infants' preference for their correctly pronounced names, confirms the strength of this preference in the Test infants. Longer LTs for CPs over MPs were found for 21 of the 30 test infants (binomial test, $p = .02$), but only for 12 of the 30 control infants (binomial test, $p = .18$). This pattern of results shows a medium effect in the test group (preference for CPs) and a small effect in the control group (preference for MPs), and a large difference between the two groups.

Moreover, a second ANOVA including the factor feature (place, roundedness, or height; all $n = 10$) in addition to the previous factors yielded no effect of feature and no interaction involving feature (all *F*s < 1), while the pronunciation × group interaction was still significant ($F(1, 54) = 14.43$, $p = .0004$, $\eta^2_p = .21$). These results establish that French-learning 5-month-olds prefer their correctly pronounced name over a one-feature mispronunciation of that name, independently of the feature tested, as opposed to control infants who show a marginal preference for the mispronunciation. The present results thus exclude the possibility that infants in the Consonant change condition did not have a preference for their correctly pronounced name due to difficulties with our testing procedure.

### *Acoustic measures*

Acoustic measures were conducted on the stimuli (see Stimuli section for details), which consisted of 28 different pairs of CPs-MPs in the Consonant change condition and 25 pairs of CPs-MPs in the Vowel change condition.

### Duration and intensity

Regarding salience, the consonants lasted 73.2 ms and were 71.4 dB loud on average, while the vowels lasted 106.9 ms and were 78.9 dB loud. Regarding discriminability within each pair of contrasted phoneme (e.g. the /v/ in Victor vs. the /z/ in Zictor), consonant CPs were on average 9.8 ms shorter (95% *CI* = [−22.2, 2.7]) and 1.1 dB louder (95% *CI* = [−3.0, 5.4]) than consonant MPs; vowel CPs were on average 2.9 ms shorter (95% *CI* = [−7.8, 2.12]) and .5 dB softer (95% *CI* = [−1.8, 0.8]) than vowel MPs. To further explore whether there were differences in salience or discriminability between the consonant and vowel conditions, two separate ANOVAs examining duration and intensity were run, with the factors of pronunciation (CP versus MP) and condition (Consonant change vs. Vowel change). In both cases, there was only a significant effect of condition with consonants being shorter (duration: $F(1, 51) = 33.29$, $p < 10^{-6}$, $\eta^2_p = .40$) and softer than vowels (intensity: $F(1, 51) = 41.35$, $p < 10^{-6}$, $\eta^2_p = .45$), hence establishing that vowels were more salient than consonants. Moreover, there were no effects of pronunciation nor a pronunciation × condition interaction, suggesting that in both conditions, CPs and MPs could not be discriminated based on duration and intensity differences (therefore, the marginal preference for MPs over CPs found in the Control group of the Vowel change condition cannot be attributed to differences in terms of duration or intensity of the first phonemes).

### Spectral measures

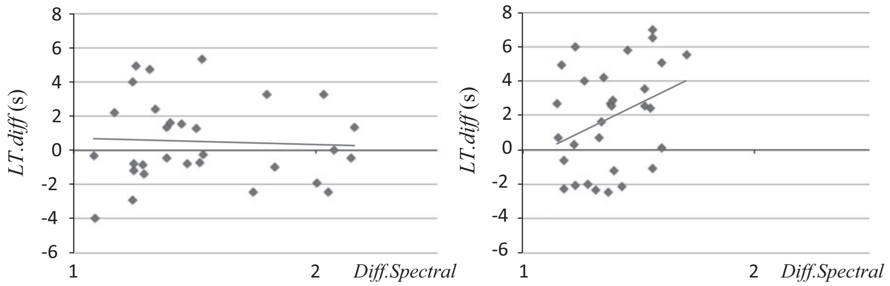
The normalized acoustic/phonetic distance (*Diff.spectral*, normalized for duration and intensity, based on MFCCs) was used to assess discriminability (as mentioned above, MFCCs are not meaningful with respect to salience). On average, *Diff.spectral* was 1.54 ($SE$ = .06) for consonant contrasts, and this was significantly higher than the same index for vowels (1.36, $SE$ = .03; $t(52) = 6.45$, $p = .01$, $\eta^2_p = .11$). This establishes that consonant contrasts were acoustically more distinct than vowel contrasts, once normalized for intensity and duration.

### *Acoustic predicates of preference measures*

We then explored the link between individual test infants' performance as attested by the difference in LTs between CPs and MPs (*LT.diff*), and three independent measures of acoustic distance between CPs and MPs: normalized duration and intensity differences (*Diff.duration* and *Diff.intensity*) and *Diff.spectral*. First, a multiple linear regression was run on all 60 test infants (30 Consonant change, 30 Vowel change) with *LT.diff* as the dependent variable and the three acoustic distances as predictors (for which there was no colinearity, all Variance Inflation Factors, $VIF$s < 3). The model did not explain a significant part of the variance in *LT.diff* ($R^2$ = .01, $R^2adjusted = -.04$; $F(3, 56) = .31$, $p = .81$), and none of the predictors significantly predicted the difference in LTs between CPs and MPs. This analysis suggests that the variability in infants' detection of an MP in their own name is not explained by differences in any of the three acoustic dimensions, at least when analyzing the consonant and vowel conditions together. However, it is possible that infants distinguish and process consonants and vowels differently (which could be supported by their differences in salience reported above) and hence that acoustic distances have different effects within each phonemic category. To explore this possibility, we ran the same regression as above but separately for each condition.

In the Consonant change condition (all $VIF$s < 3) this initial three-predictor model did not explain a significant part of the variance in *LT.diff* ($R^2$ = .10, $R^2adjusted$ = .001; $F(3, 26) = 1.00$, $p = .41$). For comparison purposes with the Vowel change condition (see below), we then ran a backward regression, which, not surprisingly, did not converge onto any model and in which none of the predictors contributed significantly to *LT.diff*. Therefore, the variance in infants' differential LTs towards CPs versus consonant MPs is not predicted by our three acoustic distances (see Figure 2, left panel, presenting the individual data for *Diff.spectral*, which is further considered in the Vowel change condition).

In the Vowel change condition (all $VIFs$ < 3), the regression model with *LT.diff* and the three predictors yielded a marginal model ($F(3, 26) = 2.51$, $p = .08$) explaining 22.5% of the variance ($R^2adjusted$ = .135; *standard error of estimate* = 2.80). In this model, *Diff.spectral* was the only significant predictor ($\beta_{spectral}$



Consonant change Condition

Vowel change Condition

**Figure 2** *Link between LT.diff and Diff.spectral in the Consonant change condition (left) and Vowel change condition (right).*

= .394, $p$ = .034). We then ran a backward regression that converged onto a significant two-predictor model ($F$(2, 27) = 3.44, $p$ = .047) resulting in the exclusion of *Diff.intensity*. This final model explained 20.3% of the variance (*$R^2$adjusted* = .144, *standard error of estimate* = 2.78) and included *Diff.spectral* and *Diff.duration* as predictors ($\beta_{spectral}$ = .369, $p$ = .042; $\beta_{duration}$ = .294, $p$ = .10). This shows that the variability of *Diff.spectral* and *Diff.duration* taken together accounts for a significant part of the variance in infants' differential LTs, and that *Diff.spectral* is a significant predictor of *LT.diff* even though the distribution of *Diff.spectral* values was narrower in the Vowel change condition than in the Consonant change condition (see Figure 2, right panel). Therefore, contrary to what was found in the Consonant change condition, the variability introduced by two acoustic distances (in particular spectral distance) in vowels partially determines French-learning 5-month-olds' preference for their correctly pronounced name over a one-feature vowel mispronunciation.

Lastly, the same three multiple linear regressions were run with the performance of Control infants as the dependent variable (*LT.diff_ctrl*) and the same three independent measures of acoustic distance between CPs and MPs: normalized duration and intensity differences (*Diff.duration* and *Diff.intensity*) and *Diff.spectral*. None of the three models explained a significant part of the variance in infants' differential LTs nor yielded any significant predictor (both conditions together: $R^2$ = .03, *$R^2$adjusted* = −.03; $F$(3, 56) = .50, $p$ = .69; Consonant condition: $R^2$ = .08, *$R^2$adjusted* = −.03; $F$(3, 26) = .74, $p$ = .54; Vowel condition: $R^2$ = .04, *$R^2$adjusted* = −.07; $F$(3, 26) = .35, $p$ = .79).

## Discussion

Previous work with adults and toddlers has shown that consonants are more important than vowels in learning and recognizing words. The present study explored whether there is an early consonant bias in one of the earliest words known by infants: their own name. French-learning 5-month-olds were tested on the impact of either a consonant or a vowel mispronunciation on their listening preference for their name. All mispronunciations involved one-feature changes (based on Dell, 1985) between two native consonants or vowels, which were expected to be discriminated by the participants. In the Consonant change condition, infants failed to show a preference for their correctly pronounced names (CPs) over consonant mispronunciations (MPs). In the Vowel change condition, infants preferred their CP names over vowel MPs, demonstrating sensitivity to vowel MPs. These findings were found independently of the consonantal (place, voicing, manner) and vocalic (place, roundedness, height) features tested. Thus, French-learning infants, tested on their sensitivity to minimal phonetic changes in one of their first words, exhibit a vowel bias at the onset of lexical processing.

Our results do not support the initial bias hypothesis (Nespor *et al*., 2003), which predicted a consonant bias at the onset of lexical processing. On the contrary, they suggest that the consonant bias is learned. This is in line with previous reports showing cross-linguistic differences, in particular the later emergence of the consonant bias in English-learning infants than in French-learning infants (Floccia *et al*., 2014; Nazzi *et al*., 2009). One way to interpret the English–French discrepant data has been to suppose a temporary disappearance of the initial consonant bias in English toddlers (U-shaped trajectory, see Floccia *et al*., 2014, for a discussion). However, the present findings contradict this idea, because even in French, a language in which the consonant bias is consistently found in toddlers (e.g. Havy & Nazzi, 2009; Nazzi, 2005; Nazzi *et al*., 2009), infants did not show this pattern. Indeed, infants did not consider consonant changes in a familiar word as lexically relevant, as clear preference responses were found only for vowel changes.

The current findings support the idea that infants have to learn the differentiated functional roles of consonants and vowels. Together with previous reports of a consonant bias at 12 to 14 months of age in Italian- and French-learning infants (Hochmann *et al*., 2011; Zesiger & Jöhr, 2011), the present findings suggest (at least in these two languages) that the time window for the emergence of a consonant bias is the second semester of life. For this learning to take place, one possibility (the lexical hypothesis, Keidel *et al*., 2007) is that infants need to acquire a sizeable lexicon to discover that consonants are statistically more informative than vowels regarding the identity of the words in the lexicon. That could be done through the computation of consonant versus vowel tiers, or consonant versus vowel phonological neighbors; using this information, infants would learn that consonants are more relevant for word learning and word processing. Another possibility (the acoustic–phonetic hypothesis, Floccia *et al*., 2014) is that the acoustic and phonetic differences between consonants and vowels provide an early cue to infants that these types of speech sounds should be processed differently. While the current study was not designed to separate these two hypotheses, some of the present findings nevertheless contribute to this issue.

Our acoustic analyses confirm that vowels are acoustically more salient than consonants both in duration and intensity (Repp, 1984). Importantly, they also reveal that vowel contrasts are spectrally *less* distinct than consonant contrasts per time unit and controlling for intensity. In addition, infants' preference responses clearly establish that consonants and vowels are processed differently in word recognition by 5 months: infants' recognition of their name was more impaired by vowel MPs than consonant MPs, and only their performance with vowel MPs was modulated by acoustic factors. However, these acoustic cues were not significant factors in the overall regression analysis, suggesting that infants might assign consonants and vowels to abstract categories independently of the acoustic factors considered here. Therefore, consonants and vowels differ on acoustic saliency (vowel advantage) and discriminability (consonant advantage), and are processed differently in a lexical task early in development.

The above observations give support to the acoustic–phonetic hypothesis in principle; however, we are left to explain why 5-month-olds nevertheless give more relevance to vowels than to consonants in the current name recognition task. From an acoustic point of view, while it is likely that 5-month-olds can discriminate (most of) the native consonant and vowel contrasts used in the present study when presented in short speech sequences, one possibility is that 5-month-olds are still better at processing acoustic details in the most salient portions of the signal, which are usually the vocalic parts, in line with well-established findings of better perception of vowels in utero and at birth (Bertoncini *et al.*, 1988; Benavides-Varela *et al.*, 2012; Granier-Deferre *et al.*, 2011). It is also possible that infants' early preference for infant-directed speech, which is characterized by large prosodic modulations mostly carried by vowels, contributes to 5-month-olds' greater reliance on vowels in the current study (Fernald, 1985; Werker & McLeod, 1989). From a phonetic/phonological point of view, another possibility is that 5-month-olds have more advanced knowledge of native phonetic categories for vowels than for consonants (Kuhl *et al.*, 1992; Werker & Tees, 1984), to a point where they have started learning native vocalic phonemic categories but not native consonantal phonemic categories (in line with the proposal by PRIMIR that phonemes are learned in a staggered fashion; Werker & Curtin, 2005). Finally, the finding that 5-month-olds only used the vocalic contrasts in this lexically related task (name recognition), while being very likely able to discriminate both consonantal and vocalic contrasts in speech perception tasks, extends to this age previous reports of a possible dissociation between phonetic discrimination and use of phonetic information at the lexical level in toddlerhood as a function of level of acquisition, task requirement, or level of processing (e.g. Nazzi, 2005; Stager & Werker, 1997).

But how will the appropriate consonant bias in lexical processing be discovered in development? As they grow older, infants' temporal resolution in sounds becomes more acute (Werner, Marean, Halpin, Spetner & Gillenwater, 1992), which might allow them to perfect their ability to perform fine-grained phonetic distinctions for shorter speech sounds (i.e. consonants) in words. Acoustic/phonetic distance per time unit was found to be larger in consonants than in vowels, which could lead infants to switch attention from the vowels to the acoustically more reliable consonants. A second scenario, related to phonetic/phonological acquisition, is that the learning of native consonantal phoneme categories around 10–12 months of age (Werker & Tees, 1984) could induce a shift in cognitive resources or attention towards consonants in word processing, in line with the PRIMIR proposal (Werker & Curtin, 2005). While these explanations are compatible with the acoustic–phonetic hypothesis, a third possibility related to the lexical hypothesis is that the consonant bias emerges with the acquisition of a sizeable lexicon, allowing infants to discover that there are more phonological neighbors obtained by a consonant than a vowel change, hence that consonants are more informative at the lexical level. One good test against this latter hypothesis would be to establish that the consonant bias is already present at 8 months, an age at which infants' limited vocabularies have little or no phonological neighbors.

To sum up, these novel results break ground in specifying the relative contribution of consonants and vowels in early word recognition, directly contradicting previous accounts of the developmental origins of the consonant bias in lexical processing. Our findings are the first to report comparative evidence of mispronunciation detection of consonants and vowels in a large set of familiar words as early as 5 months, and to ground these effects in the acoustic properties of the words being presented, which will have to be extended to more kinds of words. Importantly, 5-month-olds were found to make lexical distinctions based on minimal changes for vowels (though not for consonants) long before they have started talking in an intelligible way, supporting the notion that early lexical representations are already quite elaborate. Future studies will need to extend this finding in different ways. First, given evidence of cross-linguistic variation in the expression of the consonant bias in toddlerhood (Floccia *et al.*, 2014), the present study will need to be extended to other languages. Second, the current study focused on infants' name, which might have a special valence and status (see Hall, 2009, for a review) and might thus be processed differently from other kinds of words such as count nouns. Recent evidence suggests that this might not be the case, since French-learning 6-month-olds were also found to be more sensitive to a vocalic than a consonantal change in a word segmentation task in which the target words were unfamiliar monosyllabic count nouns (Nishibayashi & Nazzi, 2014). Future studies will have to further explore the generality of this early vocalic bias and its link to the emerging consonant bias across languages.

## Author contributions

CB, TN and CF designed the research, CB carried out the research, TF and MAD provided the acoustic analyses, CB and TN analyzed data, and CB, TN and CF wrote the paper.

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