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1 Emergence of a consonant bias during the first year of life: New evidence from own-name
2 recognition

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Abstract

19

20 Recent evidence suggests that during the first year of life, a preference for consonant
21 information during lexical processing (consonant bias) emerges, at least for some languages
22 like French. Our study investigated the factors involved in this emergence as well as the
23 developmental consequences for variation in consonant bias emergence. In a series of
24 experiments, we measured 5-, 8-, and 11-month-old French-learning infants' orientation
25 times to a consonant or vowel mispronunciation of their own name, which is one of the few
26 word forms familiar to infants at this young age. Both 5- and 8-month-olds oriented longer
27 to vowel mispronunciations, but 11-month-olds showed a different pattern, initially
28 orienting longer to consonant mispronunciations. We interpret these results as further
29 evidence of an initial vowel bias, with consonant bias emergence by 11 months. Neither
30 acoustic-phonetic or lexical factors predicted preferences in 8- and 11-month-olds. Finally,
31 counter to our predictions, a vowel bias at the time of test for 11-month-olds was related to
32 later productive vocabulary outcomes.

33 *Keywords:* lexical processing; familiar word form recognition; consonant bias;
34 French-learning infants; own-name recognition

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36 recognition

37 Adult native speakers of a variety of languages typically have a bias for consonant
38 over vocalic information during lexical processing (consonant bias; for a review see Nazzi &
39 Cutler, 2018), although this may not be the case in tonal languages (Gómez, Mok, Ordin,
40 Mehler, & Nespors, 2018; Poltrock, Chen, Kwok, Cheung, & Nazzi, 2018; Wiener &
41 Turnbull, 2016). For example, English, Dutch, and Spanish listeners are more likely to
42 change the pseudoword kebra into the real word cobra, conserving consonantal information,
43 than changing it into zebra, conserving vocalic information (Cutler, Sebastián-Gallés,
44 Soler-Vilageliu, & Ooijen, 2000; Ooijen, 1996). Such evidence of a consonant bias in lexical
45 processing is thought to reflect the underlying structure of speech and although originally
46 proposed as innate (Nespors, Peña, & Mehler, 2003), recent evidence suggests that infants
47 initially have a bias for vocalic over consonant information during lexical processing (vowel
48 bias; for a review of cross-linguistic evidence see Nazzi, Poltrock, & Von Holzen, 2016).
49 The emergence of the consonant bias may therefore reflect development of a sophisticated
50 understanding of the speech in an infants' native language and has been proposed as a
51 bootstrapping mechanism for early language acquisition. For children learning French, the
52 language where this has been most studied and also the language we focus on in the
53 current study, evidence for the consonant bias in older infants and toddlers has been robust
54 (Havy & Nazzi, 2009; Havy, Serres, & Nazzi, 2014; Nazzi, 2005; Nazzi & Bertoncini, 2009;
55 Nazzi et al., 2009; Nazzi & New, 2007; Zesiger & Jöhr, 2011), and has been extended to the
56 first year of life, in infants as young as 8 months in word segmentation (Nishibayashi &
57 Nazzi, 2016; Von Holzen, Nishibayashi, & Nazzi, 2018) and 11 months in familiar word
58 form recognition (Poltrock & Nazzi, 2015). By examining younger infants, however, two
59 studies have established that for French-learning infants, an initial vowel bias remains until
60 at least 5 months for own-name recognition (Bouchon, Floccia, Fux, Adda-Decker, &
61 Nazzi, 2015) and 6 months for word form segmentation (Nishibayashi & Nazzi, 2016). This

62 switch from a vowel to consonant bias is also reflected in the developmental trajectory of
63 infant's native sound category acquisition, which shows that vowel categories (6 months;
64 Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992) are learned earlier than consonant
65 categories (10–12 months; Werker & Tees, 1984). Yet, little is known about the factors
66 driving the differential processing of consonants and vowels during lexical processing or
67 those modulating infants' switch from an initial bias for vowels to a consonant bias or how
68 the timing of this switch relates to other aspects of language acquisition. The focus of the
69 current manuscript is to shed light on these issues by examining the developmental
70 trajectory of consonant bias emergence in French-learning infants' word form recognition.

71 Thus far, only one study has directly examined the timing of consonant bias
72 emergence using the exact same stimuli and method. In a series of word form segmentation
73 experiments, Nishibayashi and Nazzi (2016) examined the emergence of the consonant bias
74 with 6- and 8-month-old French-learning infants, finding a vowel bias in 6-month-olds but a
75 consonant bias in 8-month-olds (see Von Holzen et al., 2018 for similar ERP results with
76 8-month-olds). Other indirect evidence comes from another type of lexical processing,
77 familiar word form recognition. While word form segmentation requires short-term
78 maintenance of a newly segmented word's phonological form, word form recognition
79 requires the long-term retention of the phonological form of a familiar word.
80 French-learning infants as young as 11 months exhibit a consonant bias (Poltrock & Nazzi,
81 2015). The number of words that even younger infants recognize is comparably smaller,
82 rendering the study of word form recognition challenging. Yet, given that 5-month-olds
83 recognize their own name (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Mandel,
84 Jusczyk, & Pisoni, 1995), Bouchon and colleagues (2015) used the Headturn Preference
85 Procedure (HPP) to study phonological bias in own name recognition by French-learning
86 5-month-olds, establishing a vowel bias at this age. Combined, these studies provide
87 additional evidence that the consonant bias emerges during the latter half of the first year
88 of life, although the gap in age between 5- and 11-month-olds is rather large and the words

89 used in both studies are very different (own name versus familiar names not referring to
90 the infant).

91 The first goal of the present study, in line with Bouchon et al. (2015), is to extend the
92 developmental trajectory of the vowel to consonant bias shift, to infant's processing of their
93 own name. We begin our investigation with two ages where a vowel to consonant bias shift
94 has been previously found for unfamiliar words or pseudowords (Hochmann,
95 Benavides-Varela, Nespors, & Mehler, 2011; Hochmann, Benavides-Varela, Nespors, Mehler,
96 & Flo, 2017; Nishibayashi & Nazzi, 2016), at 5 and 8 months (Experiment 1). This
97 investigation is then extended to 11 months of age in Experiment 2, since a consonant bias
98 has been found at that age for familiar words by Poltrock and Nazzi (2015).

99 A second goal of the present study is to better understand the factors that support
100 consonant bias emergence. According to the acoustic-phonetic hypothesis (Floccia, Nazzi,
101 Luche, Poltrock, & Goslin, 2014), a vowel change interrupts lexical processing because
102 vowels are more salient than consonants. Bouchon et al. (2015) found that French-learning
103 5-month-old infants' early vowel bias may be driven by acoustic factors such as spectral
104 distance, and to a lesser extent duration difference, between the correct and mispronounced
105 vowel of their name. As development continues, however, the saliency of vowels loses
106 importance to consonants, which are processed more categorically (Fry, Abramson, Eimas,
107 & Liberman, 1962) and therefore provide a more reliable cue to lexical processing.
108 Variation in acoustic/phonetic properties, such as lexical stress which leads to vowel
109 reduction in English or the large number of vowels in Danish, has been suggested to
110 account for the cross-linguistic variation found in evidence for the consonant bias (Delle
111 Luche, Floccia, Granjeon, & Nazzi, 2016; Floccia et al., 2014; Højen & Nazzi, 2015; see
112 Nazzi et al., 2016 for a review).

113 In contrast to the acoustic-phonetic hypothesis, the lexical hypothesis was originally
114 proposed to account for the presence of a consonant bias in adults (Keidel, Jenison,

115 Kluender, & Seidenberg, 2007). According to Keidel and colleagues, it is the experience
116 with the French lexicon, that leads French adults to discover that consonant information is
117 more informative for lexical processing than vowel information. Keidel et al. (2007)
118 analyzed the consonant and vowel structure of French CVCVCV words from the Lexique
119 database (New, Pallier, Brysbaert, & Ferrand, 2004). They found that a given word
120 (e.g. *numéro*, /ny.me.ʁo/) is almost 40% more likely to be identified given only its consonant
121 tier information (/n.m.ʁ/) than its vowel tier information (y.e.o). For a consonant bias to
122 emerge, an infant's exposure to their native language must reach some unknown threshold
123 whereby the informativeness of consonants compared to vowels for word identity becomes
124 clear. This may come through a certain lexical size or more specifically the structure of the
125 early infant lexicon that cues infants into the usefulness of consonants for lexical
126 processing. Yet, in the few studies where vocabulary scores have been collected, there has
127 been no evidence for a relationship between overall lexicon size and magnitude of the
128 consonant bias (Poltrock & Nazzi, 2015) and even evidence that a larger lexicon is related
129 to greater sensitivity to vowel mispronunciations in English-learning 12-month-olds (Mani
130 & Plunkett, 2011), a finding that runs counter to the predictions of a lexically-based
131 consonant bias emergence. However, the lexical hypothesis is not based on the number of
132 words known, but instead the statistical information provided by consonants and vowels
133 across known words. To better capture this consonant and vowel structure, Hochmann et
134 al. (2011) examined the words French- and Italian-learning infants are likely to know at
135 this early stage (using CDI norming data), revealing that already at 8 months, infants
136 typically know a greater proportion of words that have unique consonant compared to
137 vowel tiers (e.g. *canapé* /kanape/: /k.n.p/ vs. /a.a.e/). Yet, this analysis does not account
138 for the wide variation in the early infant lexicon (Frank, Braginsky, Yurovsky, &
139 Marchman, 2017), nor does it connect early lexical structure to the consonant bias in
140 individual infants, which will be explored in the present study.

141 The final goal of this study is to examine the relationship between early variation in

142 the consonant bias and later vocabulary outcomes over the second year of life. Both the
143 acoustic/phonetic and lexical hypotheses predict emergence of the consonant bias resulting
144 from accumulating linguistic input over the first year of life. Considering that linguistic
145 input varies across infants and that variability in individual performance in laboratory
146 tasks is often large (Kuhl et al., 2006), there is reasonable expectation of variation in the
147 evidence of the consonant bias in a given age group. This variation may be related to the
148 acoustic/phonetic and/or lexical factors described above, highlighting how differences in
149 the input may contribute to earlier or later emergence of the consonant bias in individual
150 infants. Furthermore, this variation in consonant bias emergence may have consequences
151 for subsequent linguistic development. One may thus expect that word learning and
152 recognition may be facilitated in infants developing an earlier or stronger consonant bias,
153 leading to better vocabulary outcomes later in development.

154 **Experiment 1: 5- and 8-month-olds**

155 In Experiment 1, we sought to extend previous evidence of a switch from vowel to
156 consonant bias during the first year of life in unfamiliar words (Hochmann et al., 2011,
157 2017; Nishibayashi & Nazzi, 2016) to familiar words, specifically own-name recognition.
158 Although the experiment was inspired by Bouchon et al. (2015), it differs from it because,
159 rather than comparing correct pronunciations with consonant or vowel mispronunciations
160 in two separate experiments, we used a conflict task (Nishibayashi & Nazzi, 2016) and
161 directly compared how long infants' attend to a consonant or vowel mispronunciation of
162 their own name within a single experiment. If infants process consonant and vowel
163 information differently during lexical processing, we expect them to differentially orient to
164 the two kinds of mispronunciations. Related tasks with French-learning infants find that
165 infants orient longer to word forms that best match the word form they are familiar or
166 have been familiarized with (Bouchon et al., 2015; Nishibayashi & Nazzi, 2016). For
167 example, orienting longer to a vowel compared to a consonant mispronunciation would

168 indicate a consonant bias, as the vowel mispronunciation conserves consonant information.
169 Our study differs from these in that we use the infants' own names (contrary to
170 Nishibayashi & Nazzi, 2016) and familiarize infants with the correct pronunciation of their
171 name (contrary to Bouchon et al., 2015). As a consequence of either or both of these
172 differences, we may change the difficulty of the present task, which may reverse the effects
173 as predicted by the model of Hunter and Ames (1988). The results of the 5-month-olds, for
174 which we expect a vowel bias as found for own name recognition by Bouchon et al. (2015)
175 should clarify this issue.

176 Based on previous evidence from word segmentation (Nishibayashi & Nazzi, 2016;
177 Von Holzen et al., 2018), we may expect 8-month-olds to show a consonant bias during
178 own-name recognition. However, word form segmentation only requires the short-term
179 retention of a word form, whereas word form recognition requires the long-term
180 maintenance of a word form. Furthermore, infant's own names are among some of the
181 earliest word forms recognized, with evidence for recognition as young as 4.5 months
182 (Mandel et al., 1995). As a result, these words are heard in a variety of intonational
183 contexts. Considering that intonation is carried by vowels, this may render the processing
184 of the infant's own-name more resistant to the emergence of the consonant bias. If this is
185 the case, we may find that 8-month-olds do not exhibit a consonant bias in own-name
186 recognition.

187 In addition to examining the differential processing of consonants and vowels in these
188 two age groups, we also examined whether this processing is modulated by
189 acoustic-phonetic and/or lexical factors. Similar to Bouchon et al. (2015) we measured the
190 duration, intensity, and spectral distance between correct and mispronounced phonemes
191 (both consonant and vowel) in the own-name stimuli presented to infants. Unlike Bouchon
192 et al. (2015), however, we present each infant with both consonant and vowel
193 mispronunciations (test phase) and correct pronunciations (pre-test phase). In addition to
194 demonstrating the correct pronunciation to the infant, this also allowed for an examination

195 of performance in relation to acoustic/phonetic factors of both consonants and vowels
196 within each infant. We also measured the overall lexicon size as well as the number of
197 unique consonant and vowel tiers in known words of each of the 8-month-old infants we
198 tested. This could not be done for 5-month-olds since these inventories are not used before
199 8 months, due to parental difficulties in identifying, with reliability, the few words their
200 infants might know.

201 Finally, to capture the developmental consequences of individual variation in the
202 emergence of the consonant bias, we sent follow-up vocabulary questionnaires to the
203 8-month-old infant participants when they were 13, 16, and 24 months of age. Sensitivity
204 to both vowel and consonant mispronunciations in word segmentation at 8 months has
205 been found to predict growth in word production over these ages (Von Holzen et al., 2018).
206 In the current study, however, we measure the preference for consonant compared to vowel
207 information, which may provide a more accurate assessment of whether consonant bias
208 emergence is related to later vocabulary outcomes.

209 **Methods**

210 **Participants.** Twenty-seven monolingual, French-learning 5-month-old infants
211 (mean age = 165.85 days, age range = 156 – 179 days, 13 females) and 27 monolingual
212 French-learning 8-month-old infants (mean age = 260.41 days, age range = 248 – 274 days,
213 15 females) were included in the analysis. The name and amount of exposure to the name
214 for each infant was determined in a pre-visit telephone conversation, which ensured that the
215 correct, individual name was noted. Only infants who had at least 80% exposure to French
216 and to an individual name were included. All parents reported that their infant was born to
217 term and healthy, with no reports of cognitive, visual, or hearing impairment. The present
218 study was conducted according to guidelines laid down in the Declaration of Helsinki, with
219 written informed consent obtained from a parent or guardian for each infant before any
220 assessment or data collection. All procedures involving human subjects in this study were

221 approved by the Ethics Committee of CERES (No. 2011-14, 18 October 2011) at the Paris
222 Descartes University. An additional fourteen 5-month-old infants were tested but excluded
223 from the final data set due to fussiness (8), having two consecutive trials with insufficient
224 orientation times (2), three or more insufficient orientation times overall (1), or being an
225 outlier (3; difference between consonant and vowel mispronunciations 2 SD below or above
226 the group mean, as in Bouchon et al., 2015). An additional eight 8-month-old infants were
227 tested but excluded from the final data set due to fussiness (1), having two consecutive
228 trials with insufficient orientation times (3), three or more insufficient orientation times
229 overall (2), or being an outlier (2; see below). Families were recruited from Paris, France, a
230 large metropolitan city, using addresses obtained by the public birth registry and letters
231 were sent to eligible parents inviting them to participate. The socio-economic status of
232 families participating in studies in this laboratory is typically upper-middle class¹. Families
233 were compensated by a participation diploma with their child’s picture.

234 **Stimuli.** A set of stimuli recordings was prepared for each infant, corresponding to
235 a correct pronunciation (CP), consonant mispronunciation (cMP), and vowel
236 mispronunciation (vMP) of their own name. Twenty-one of the 5-month-old and 23 of the
237 8-month-old infants had names beginning with a consonant; for these infants, the cMP was
238 the initial consonant and the vMP was the first vowel to occur in the name. The remaining
239 six 5-month-olds and four 8-month-olds had names beginning with a vowel; for these
240 infants the vMP was the initial vowel and the cMP was the first consonant to occur in the
241 name. A table of infant names and consonant and vowel mispronunciations can be found in
242 Appendix A. The cMPs and vMPs of the names always consisted of a 1-feature change,
243 with the three possible feature changes for consonants (place, manner, voicing) and for
244 vowels (place, height, roundness) counterbalanced across infants in each age group for a

¹ As pointed out by an anonymous reviewer, the homogeneous socio-economic status of our samples in Experiments 1 and 2 limits their generalizability to the broader population. Future studies should consider the potential impact that socio-economic status may have on the developmental trajectory of consonant bias emergence.

245 total of nine possible combinations, with three infants per combination. For each name, a
246 female, native French speaker recorded 15 tokens each of the cMP and vMP names and 10
247 tokens of the CP. For each MP, two 24-second files of all 15 tokens were created using the
248 same tokens in reverse order of one another for the two files. For each CP, two 16-second
249 files of all 10 tokens were created using the same tokens in reverse order of one another for
250 the two files.

251 **Behavioral Task.** The Head-turn Preference Procedure (HPP) used in the current
252 study was similar to that of Bouchon et al. (2015). Each session started with two CP
253 pre-test trials, one for each flashing red light on the sides of the booth, which allowed the
254 infants an opportunity to practice one head-turn to each side. The purpose of these
255 pre-test trials was to demonstrate to the infants the correct pronunciation of their name, as
256 pronounced by our speaker; it was not intended to habituate the infants. Furthermore,
257 these trials provided the correct phonemes with which to compare the acoustic
258 characteristics of the mispronounced phonemes (see below). Once infants had listened to
259 20 repetitions of the CP of their name (10 in each of the 2 pre-test trials), the test phase
260 began.

261 The test phase consisted of two blocks of four trials each (8 trials total). Each block
262 presented the two sound files for each cMP and vMP and order of the sound files within
263 each block was randomized. In total, therefore, infants heard four cMP trials and four vMP
264 trials (side of presentation was counterbalanced within blocks). Stimuli played continuously
265 until completion or stopped immediately if the infant failed to maintain the head-turn for
266 two consecutive seconds. If the infant turned away from the target flashing light by 30° in
267 any direction for less than 2 seconds, the trial continued without interruption, but the time
268 spent orienting away from the target flashing light (as determined by the experimenter's
269 release of the corresponding button on the response box) was automatically calculated and
270 subtracted from the total orientation time by the computer program. The maximum
271 orientation time for a given trial was the duration of the entire speech sample (24 s). If a

272 trial lasted less than 1.5 s (defined as insufficient orientation time), the trial was repeated
273 and the original orientation time was discarded. The dependent variable was mean
274 orientation time for each trial. Infants with a mean difference score (cMP – vMP) greater
275 or less than 2 standard deviations from the group mean were removed as outliers (Bouchon
276 et al., 2015).

277 **Acoustic analysis of the stimuli.** Similar to Bouchon et al. (2015), to capture
278 acoustic/phonetic distance, we measured three acoustic dimensions of the contrasted
279 phonemes (correct vs. mispronunciation for both consonants and vowels) in order to
280 characterize their differences: duration, intensity, and Mel Frequency Cepstral Coefficients
281 (MFCCs; measure of spectral distance). Contrasted phonemes were manually segmented
282 using Praat (Boersma & Weenink, 2016) for the first token in the set of tokens for CP
283 (correct consonant, correct vowel), cMP (mispronounced consonant), and vMP
284 (mispronounced vowel) words. The remaining contrasted phonemes in each set of tokens
285 were then automatically located using dynamic time warping (DTW; Sakoe & Chiba, 1978)
286 in a custom MATLAB (“MATLAB and Statistics Toolbox Release 2014b,” n.d.) script.
287 DTW is a speech comparison method that automatically determines the optimal temporal
288 matching between two speech patterns (detecting segment similarities) independently of
289 duration and speech rate.

290 Duration and intensity of each contrasting phoneme were measured using a custom
291 Praat (Boersma & Weenink, 2016) script, which calculated a normalized difference score
292 for both consonant and vowel contrasts. For example, the mean intensity of the contrasting
293 consonant in the cMP was subtracted from the mean intensity of the contrasting consonant
294 in the CP, and divided by their mean (*Cdiff.intensity*). The same procedure was done for
295 the contrasting vowel intensity (*Vdiff.intensity*), and duration (*Cdiff.duration*,
296 *Vdiff.duration*). A positive difference score indicates that the correct pronunciation was
297 more intense, or longer than the mispronunciation. MFCCs were measured for each
298 contrasting phoneme using a custom Matlab script (for details on the procedure, see

299 Bouchon et al., 2015). The ratio of the mean-cross-category distance between the 10 CPs
300 and the 15 MPs (D_{cross}) of a given pair and the mean internal variability within the 10
301 CPs ($D_{withinCP}$) and within the 15 MPs ($D_{withinMP}$) was calculated for both consonants
302 ($C_{diff.spectral}$) and vowels ($V_{diff.spectral}$). For these measurements, a larger difference
303 score indicates that the distance between the two pronunciations was spectrally larger.

304 **Vocabulary questionnaire (8-month-old infants).** At the time of their visit,
305 parents of the 8-month-old infants were asked to complete the French Communicative
306 Developmental Inventory: Words and Gestures for ages 8 to 16 months (Kern & Géraldine,
307 2003). Parents completed the questionnaire at home on paper and brought it to their
308 appointment, mailed it back, filled out a pdf and sent it by email, or filled out the
309 questionnaire online. To examine how infants' vocabulary scores grew with time, parents
310 were asked to complete the same questionnaire when their child was 13 months, as well as
311 the French CDI: Words and Phrases for ages 16 to 30 months (Kern, 2003) when their child
312 was 16 and 24 months. Parents were sent a reminder by email to fill out the questionnaire
313 at each target age (13, 16, 24). The top half of Table 1 includes a summary of the number
314 of vocabulary questionnaires returned and reported words comprehended and produced.

315 (Insert Table 1 about here)

316 To assess whether the consonant and/or vowel structure of an individual infant's
317 lexicon is related to their preference for cMPs or vMPs, we calculated the number of words
318 comprehended as well as a consonant and a vowel proportion score for each infant. We use
319 comprehension as opposed to production because infants at this age are more likely to
320 comprehend than produce words, allowing for more individual variability in the calculation.
321 After determining the number of words comprehended for each infant, we calculated the
322 number of unique consonant and vowel tiers in these known words using the phonetic
323 transcriptions from the Lexique database (New et al., 2004). For example, an infant who
324 knows the words bain ($/b\tilde{\epsilon}/$), chien ($/fj\tilde{\epsilon}/$), and merci ($/m\epsilon\tilde{\epsilon}si/$) would have three unique
325 consonant tiers, as all three words contain different consonant sequences ($/b/$; $/fj/$;

326 /m.ʁ.s/), but two unique vowel tiers, as bain and chien share the same vowel sequence
327 (/ɛ̃/), which is different than merci (/ɛ.i/). To achieve consonant and vowel proportion
328 scores, we then divided the number of unique (consonant or vowel) tiers by the number of
329 known words. In our example, the infant would have a consonant tier proportion score of 1
330 (3/3) and a vowel tier proportion score of .667 (2/3). The number of words comprehended,
331 consonant proportion score, vowel proportion score were included to evaluate the role of
332 lexical factors in the consonant bias.

333 Finally, to evaluate the role of early consonant bias emergence on later vocabulary
334 outcomes, we calculated total number of words produced at each age measured (8, 13, 16
335 and 24 months). We use production because this measurement was available at all four
336 ages, whereas comprehension was only available at ages 8 and 13 months.

337 Results

338 **Orientation time.** The raw orientation times (OTs) were not normally distributed
339 and were therefore log-transformed (LogOT; Csibra, Hernik, Mascaro, Tatone, & Lengyel,
340 2016). LogOTs were analyzed with linear mixed effects models, using R (R Core Team,
341 2018) and the package lme4 (Bates, Maechler, Bolker, & Walker, 2015). Fixed effects were
342 Type of mispronunciation (cMP, vMP), Age (5 months, 8 months), and Order (whether the
343 test trial was the 1st, 2nd, 3rd, or 4th instance of that mispronunciation). Random
344 intercepts for Trial number (1-8) and for participant, including a random slope by Type,
345 were included. All fixed effects were coded with contrast coding and the fixed effect of Trial
346 was mean centered. The full equation was: $\log\text{OT} \sim \text{Age} \times \text{Type} \times \text{Order} + (1 + \text{Type} \mid$
347 $\text{Participant}) + (1 \mid \text{Trial})$. Significance was assessed via model comparison with an alpha of
348 0.05 using the drop1 function (Chambers, 1992). The resulting best fitting model is
349 interpreted here and a table of these results can be found in Appendix B (Table B1).

350 The two left panels of Figure 1 plot infants' orientation times (logOT) for cMP and

351 vMPs over all Orders separately for 5- and 8-month-old infants. The results of the model
352 revealed a significant main effect of Order ($\chi^2(1) = 21.24, p < .001$), showing that as the
353 experiment progressed, orientation times decreased ($\beta = -0.15, SE = 0.03$). The effect of
354 Age was also significant ($\chi^2(1) = 30.47, p < .001$), showing that overall 5-month-olds
355 oriented longer than 8-month-olds ($\beta = -0.68, SE = 0.11$). Critically, the effect of Type
356 was significant ($\chi^2(1) = 5.06, p = .02$), showing that infants oriented longer for vowel
357 mispronunciations compared to consonant mispronunciations ($\beta = -0.13, SE = 0.06$).
358 There were no significant interactions between Age, Type, and Order

359 (Insert Figure 1 about here)

360 **Acoustic measurements.** A summary of the means and standard deviations of
361 the intensity and duration measurements, as well as the difference scores for intensity,
362 duration, and spectral measurements is given in Table 2. Below, we report a series of linear
363 mixed effects models that analyzed whether these measurements differed for the consonants
364 and vowels in the recording stimuli.

365 (Insert Table 2 about here)

366 ***Duration and intensity measurements.***

367 To quantify any saliency difference in the recorded stimuli, mean values for duration
368 and intensity for each contrasted phoneme were analyzed using separate linear mixed
369 effects models with the fixed effects Pronunciation (CP, MP) and Type of contrast (vowel,
370 consonant) and participant as a random intercept. Type of contrast was significant for
371 both duration ($\beta = -19.11, SE = 4.5, p < .001$) and intensity ($\beta = -16.17, SE = 1.35, p <$
372 $.001$), indicating that consonants were significantly shorter and softer than vowels. This
373 pattern is similar to that of Bouchon et al. (2015) and suggests that vowels were more
374 salient than consonants. The lack of an effect of Pronunciation or an interaction between
375 Pronunciation and Type of contrast for both duration and intensity, however, suggests that
376 cMPs and vMPs could not be discriminated from their respective CPs based on duration

377 and intensity differences.

378 ***Spectral measurements.***

379 In contrast to duration and intensity, the normalized acoustic/phonetic distance
380 (MFCCs) assesses the acoustic distinctiveness of the contrasted phonemes. Diff.spectral for
381 each contrasted phoneme pair (CP vs MP) was analyzed using a linear mixed effects model
382 with the fixed effect Type of contrast (vowel, consonant) and participant as a random
383 intercept. Type of contrast was not significant ($\beta = 0.02$, $SE = 0.05$, $p = .73$). Spectral
384 distance of consonant and vowel contrasts were not overall distinct from one another in the
385 recordings presented to infants in Experiment 1, contrary to Bouchon et al. (2015) who
386 found greater spectral distinctiveness for consonant contrasts.

387 **Acoustic predictors of orientation time.** To assess the influence of acoustic
388 characteristics on orientation time for cMPs or vMPs, a linear mixed effects model was
389 computed. To reduce the number of estimated effects, the fixed effect of Order was
390 removed. Mean difference scores (CP – MP) for each acoustic measurement were calculated
391 for both consonants and vowels (*Cdiff.Intensity*, *Vdiff.Intensity*, *Cdiff.Duration*,
392 *Vdiff.Duration*, *Cdiff.Spectral*, *Vdiff.Spectral*). Fixed factors included Age (5 months, 8
393 months), Type of mispronunciation (cMP, vMP), and the 6 acoustic measurements. In the
394 full model, each acoustic difference score was allowed to interact with each possible
395 combination of Age and Type (e.g. *Cdiff.Intensity* X Age, *Cdiff.Intensity* X Type,
396 *Cdiff.Intensity* X Age X Type, etc.). Random intercepts for Trial (1-8) and for participant,
397 including a random slope by Type, were included. Significance was assessed via model
398 comparison with an alpha of .05 using the drop1 function (Chambers, 1992). The resulting
399 best fitting model is interpreted here and a table of these results can be found in Appendix
400 B (Table B2).

401 The resulting best fitting model included main effects of Age and *Vdiff.Spectral*. The
402 effect of Age was significant ($\chi^2(1) = 31.56$, $p < .001$), reflecting the previous result

403 showing that 5-month-olds had longer orientation times than 8-month-olds ($\beta = -0.72$, SE
404 $= 0.11$). The effect *Vdiff.Spectral* was also significant ($\chi^2(1) = 5.96$, $p = .01$), showing
405 that infants with a smaller spectral difference between the MP and CP vowel in their name
406 had longer orientation times overall, regardless of whether the trial presented a vMP or a
407 cMP. Without a significant interaction between any of the acoustic measurements and
408 Type, this model provides no evidence for a role of acoustic characteristics in the
409 preference for vMPs compared to cMPs.

410 **Lexical predictors of orientation time.** The 21 8-month-old infants for whom
411 vocabulary questionnaires were returned at 8 months knew on average 22.90 words (SD =
412 35.85) at this age, which consisted of an average of 20.43 unique consonant tiers (SD =
413 30.42) and 15.57 unique vowel tiers (SD = 19.83). The proportion of unique consonant
414 tiers (M = 0.95; SD = 0.06) was significantly greater than the proportion of unique vowel
415 tiers (M = 0.88; SD = 0.16), $t(17) = 2.66$, $p = .02$ (3 infants reportedly knew no words at
416 age 8 months, their data was removed to conduct this t-test).

417 To assess the influence of lexical factors at 8 months, derived from vocabulary scores,
418 on preference for vMPs or cMPs, a linear mixed effects model was computed. We included
419 the fixed effect Type of mispronunciation (cMP, vMP), but not Order, to reduce the
420 number of estimated effects, or Age, as this model was only fit to data from 8-month-olds
421 (from whom we collected vocabulary scores). We also added fixed effects of the
422 log-transformed total number of words comprehended (Comp), proportion of known words
423 with unique consonant tiers (Cprop), and proportion of known words with unique vowel
424 tiers (Vprop). All fixed effects were coded with contrast coding and the lexical scores were
425 mean centered. Random intercepts for Trial (1-8) and for participant, including a random
426 slope by Type, were included. The full equation was: $\log\text{OT} \sim \text{Type} + \text{Comp} + \text{Cprop} +$
427 $\text{Vprop} + \text{Type:Comp} + \text{Type:Cprop} + \text{Type:Vprop} + (1 + \text{Type} \mid \text{Participant}) + (1 \mid$
428 $\text{Trial})$. Significance was assessed via model comparison with an alpha of 0.05. The resulting
429 best fitting model is interpreted here and a table of these results can be found in Appendix

430 B (Table B3).

431 Model comparison revealed no significant effects, all effects and interactions being
432 eliminated. This fails to provide evidence that the measured lexical factors influenced
433 infants' orientation times for vMPs or cMPs.

434 **Relationship between CV preference and later vocabulary.** We next
435 examined the relationship between infants' orientation times for vMPs or cMPs and word
436 production at 8, 13, 16, and 24 months. Of the 27 infants included in the final sample, 24
437 completed a vocabulary questionnaire for at least one age. Each infants' productive
438 vocabulary score (Prod.z; z-score transformed) was submitted to a mixed effects model. To
439 capture whether later productive vocabulary was related to longer orientation times for
440 vMPs or cMPs at 8 months, the mean OT for vMPs was subtracted from cMPs, creating a
441 difference score (*OT.diff*). The effect of *OT.diff* as well as the interaction between *OT.diff*
442 and Age of vocabulary measurement (8, 13, 16, 24) were included as fixed factors and a
443 random intercept for participant. The full equation was: $\text{Prod.z} \sim \text{Age} \times \text{OT.diff} + (1 \mid$
444 $\text{Participant})$. The resulting best fitting model is interpreted here and a table of these
445 results can be found in Appendix B (Table B4). Only effects of *OT.diff* or interactions
446 with *OT.diff* will be interpreted.

447 The results of the model revealed no significant main effect of or interaction with
448 *OT.diff*. A summary of the vocabulary scores for infants with a positive *OT.diff* score
449 (cMP preference) and a negative *OT.diff* score (vMP preference) are given in Table 3.

450 Discussion

451 Experiment 1 measured 5- and 8-month-old infants' orientation times for consonant
452 (cMPs) and vowel mispronunciations (vMPs) of their own-name. Previous studies showed
453 evidence of a vowel bias at 5/6 months (Bouchon et al., 2015; Nishibayashi & Nazzi, 2016)
454 while 8-month-olds exhibit a consonant bias (Nishibayashi & Nazzi, 2016), and we

455 expected a similar change if the timing of emergence of the consonant bias is the same for
456 familiar and unfamiliar words. Yet, the results of Experiment 1 show that both 5- and
457 8-month-olds show the same pattern of results, with log-transformed orientation times
458 (LogOT) longer to vowel compared to consonant mispronunciations. This unexpected lack
459 of a difference between 5- and 8-month-olds makes an interpretation of these results
460 difficult. Given previous evidence that French-learning infants orient longer to novel word
461 forms that are similar to more familiar or familiarized word forms, then orienting longer to
462 a vowel compared to a consonant mispronunciation would indicate a consonant bias
463 because the vowel mispronunciation conserves the consonant information of the name. If
464 this is the case, then Experiment 1 would provide evidence of a consonant bias at the
465 youngest age tested to-date, 5 months.

466 Interpretation of the results of Experiment 1 to indicate a consonant bias at 5
467 months, however, would be in conflict with Bouchon et al. (2015) who found a vowel bias
468 at the same age of 5 months for the same kind of words (own-name). An alternative
469 explanation for the results would be that infants attend more to a novel word form with a
470 more novel change, listening longer to mispronunciations that change the identity of the
471 word form according to their bias. If this is the case, listening longer to a vowel
472 mispronunciation would indicate a vowel bias. However, this interpretation suggests that
473 8-month-olds maintain a vowel bias longer than suggested by previous studies examining
474 unfamiliar words (Nishibayashi & Nazzi, 2016; Von Holzen et al., 2018), at least in the
475 current testing conditions.

476 According to Hunter and Ames (1988), longer familiarization times and low task
477 difficulty are likely to elicit longer looks towards stimuli that present a novel change. Unlike
478 Bouchon et al. (2015), we familiarized infants with a correct pronunciation of their name
479 (not measuring their orientation time to the correct pronunciation) and tested infants on
480 their preference for consonant and vowel mispronunciations. Familiarizing with the correct
481 pronunciation of infants' names may have increased infants interest in stimuli with a more

482 novel change whereas testing infants on both consonant and vowel mispronunciations may
483 have raised task difficulty, as it requires comparison of two changes instead of one. Based
484 on the results of Experiment 1, it is not possible to determine which alternative is the case.

485 The results of Experiment 1 therefore leave us with two puzzles to solve. First, which
486 conclusion should we draw from these results, a consonant bias (attending longer to words
487 that are more similar to familiar stimuli) or a vowel bias (attending longer to words that
488 are more novel in comparison to familiar stimuli)? Second, when does a switch from a
489 vowel to consonant bias occur when processing one's own name? Previously, 11-month-olds
490 have shown a consonant bias when tested on recognition of familiar word forms (Poltock
491 & Nazzi, 2015) and we therefore expect them to also exhibit a consonant bias in own-name
492 recognition. By testing 11-month-olds on the same task as the infants tested in Experiment
493 1, their responses should help us solve the above two questions. If 11-month-old infants
494 show the same pattern of results as those infants tested in Experiment 1, listening longer to
495 vowel compared to consonant mispronunciations, this would indicate that all three age
496 groups exhibit a consonant bias. If 11-month-olds show an different pattern, however, it
497 would indicate that the 5- and 8-month-olds tested in Experiment 1 exhibited a vowel bias
498 and establish that the switch from a vowel to consonant bias occurs between 8- and
499 11-months for own name recognition.

500 Finally, acoustic/phonetic as well as lexical factors were not found to modulate
501 orientation times to consonant or vowel mispronunciations in 5- and 8-month-olds. These
502 null results run counter to the predictions of both the acoustic/phonetic (Flocchia et al.,
503 2014) and lexical (Keidel et al., 2007) hypotheses and do not replicate the findings of
504 Bouchon et al. (2015). We also failed to reveal a link between orientation times for
505 consonant or vowel mispronunciations at 8 months and later vocabulary outcomes. In
506 Experiment 2, we examine these factors in 11-month-olds' orientation times for consonant
507 and vowel mispronunciation and discuss the full results in the General Discussion.

Experiment 2: 11-month-olds

508

509 In Experiment 2, we examined the emergence of a consonant bias in French-learning
510 11-month-olds using the same task as Experiment 1. The purpose of this experiment was
511 to specify the correct interpretation of the results for Experiment 1 as well as test whether
512 the switch from vowel to consonant bias occurs between 8- and 11-months for own name
513 recognition. Similar to Experiment 1, we also examined the role of acoustic and lexical
514 factors in orientation times for consonant and vowel mispronunciations for 11-month-olds,
515 as well as whether the orientation times for consonant and vowel mispronunciations at this
516 age predicts later vocabulary outcomes.

517 Methods

518 **Participants.** For Experiment 2, 27 monolingual, French-learning 11-month-old
519 infants were included in the analysis (mean age = 352.56 days, age range = 336 – 363 days,
520 18 females). Participants were recruited in the same way as Experiment 1. Only infants
521 who had at least 80% exposure to French and to an individual name were included
522 (determined in a pre-visit telephone conversation). All parents reported that their infant
523 was born to term and healthy, with no reports of cognitive, visual, or hearing impairment.
524 An additional 12 infants were tested but excluded from the final data set due to fussiness
525 (4), having two consecutive trials with insufficient orientation times (1), three or more
526 insufficient orientation times overall (5), or being an outlier (2; difference between
527 consonant and vowel mispronunciations 2 SD below or above the group mean, as in
528 Bouchon et al., 2015).

529 **Stimuli, behavioral task, and acoustic analysis of the stimuli.** Stimuli
530 preparation, the behavioral task, and acoustic analyses for Experiment 2 were identical to
531 that of Experiment 1. Twenty-one of the infants had names beginning with a consonant
532 and 6 beginning with a vowel. Two infants shared the same name and mispronunciation,

533 leading to a total of 25 names used in Experiment 2. A table of infant names (CP) and
534 consonant (cMP) and vowel (vMP) mispronunciations can be found in Appendix C.

535 **Vocabulary questionnaire.** As in Experiment 1, at the time of their visit and at
536 13 months, parents were asked to complete the French Communicative Developmental
537 Inventory: Words and Gestures for ages 8 to 16 months (Kern & Géraldine, 2003) and the
538 French CDI: Words and Phrases for ages 16 to 30 months (Kern, 2003) at 16 and 24
539 months. As in Experiment 1, parents of infants tested in Experiment 2 had the option of
540 completing the questionnaire on paper and bringing it to their appointment or mailing it
541 back, filling out a PDF form and returning it by email, or filling out the questionnaire
542 online. A reminder was sent to parents by email to fill out the questionnaire at each target
543 age (13, 16, 24). The bottom of Table 1 includes a summary of the number of vocabulary
544 questionnaires returned and words comprehended and produced.

545 Results

546 **Orientation time.** The raw OTs were not normally distributed and were therefore
547 log-transformed (logOT; Csibra et al., 2016). Similar to Experiment 1, LogOTs were
548 analyzed with linear mixed effects models, including the fixed effects of Type of
549 mispronunciation (cMP, vMP) and Order (whether the test trial was the 1st, 2nd, 3rd, or
550 4th instance of that mispronunciation). The full equation was: $\log\text{OT} \sim \text{Type} \times \text{Order} +$
551 $(1 + \text{Type} \mid \text{Participant}) + (1 \mid \text{Trial})$. As in Experiment 1, significance was assessed via
552 model comparison with an alpha of .05 using the drop1 function (Chambers, 1992). The
553 resulting best fitting model is interpreted here and a table of these results can be found in
554 Appendix D (Table D1).

555 The rightmost panel of Figure 1 plots infants orientation times (logOT) for cMP and
556 vMPs over all Trials for the 11-month-old infants. The results of the best fitting model
557 revealed a significant main effect of Type ($\chi^2(1) = 8.75, p < .01$), showing infants oriented
558 longer for cMPs compared to vMPs ($\beta = 0.61, \text{SE} = 0.2$). The interaction Type by Order

559 was also significant ($\chi^2(1) = 10.56, p < .01$). At the beginning of the experiment, infants
560 oriented longer to cMPs, but orientation times declined rapidly as the experiment
561 progressed while orientation times to vMPs stayed fairly level throughout the experiment
562 ($\beta = -0.24, SE = 0.07$). The effect of Order was not significant.

563 **Acoustic measurements.** A summary of the means and standard deviations of
564 the intensity and duration measurements, as well as the difference scores for intensity,
565 duration, and spectral measurements is given in Table 2. Below, we report a series of linear
566 mixed effects models that analyzed whether these measurements differed for the consonants
567 and vowels in the recording stimuli.

568 *Duration and intensity measurements.*

569 As in Experiment 1, mean for duration and intensity for each contrasted phoneme
570 were analyzed using separate linear mixed effects models with the fixed effects
571 Pronunciation (CP, MP) and Type of contrast (vowel, consonant) and participant as a
572 random intercept. Type of contrast was significant for both duration ($\beta = -25.9, SE =$
573 $8.54, p < .01$) and intensity ($\beta = -12.61, SE = 2.11, p < .001$), indicating that consonants
574 were significantly shorter and softer than vowels. There were no effects of Pronunciation or
575 interactions between Type and Pronunciation, indicating that cMPs and vMPs could not
576 be discriminated based on duration and intensity differences. This pattern is similar to
577 that of Bouchon et al. (2015) and suggests that vowels were more salient than consonants.

578 *Spectral measurements.*

579 As in Experiment 1, *Diff.spectral* for each contrasted phoneme pair (CP vs MP) was
580 analyzed using a linear mixed effects model with the fixed effect Type of contrast (vowel,
581 consonant) and participant as a random intercept. Type of contrast was not significant (β
582 $= -0.04, SE = 0.09, p = .73$). Consonant and vowel contrasts were not acoustically distinct
583 from one another in the recordings presented to infants in Experiment 2. Although this is
584 similar to the results of the spectral measurements of Experiment 1, it is different than

585 Bouchon et al. (2015) who found greater spectral distinctiveness for consonant contrasts.

586 **Acoustic predictors of orientation time.** To assess the influence of acoustic
587 characteristics of consonant and vowels on orientation time, a linear mixed effects model
588 was computed as in Experiment 1. The only deviation was the removal of the fixed factor
589 Age, as only the data from 11-month-olds were included in this analysis. Significance was
590 assessed via model comparison with an alpha of .05 using the drop1 function (Chambers,
591 1992). The resulting best fitting model is interpreted here and a table of these results can
592 be found in Appendix D (Table D2).

593 Model comparison revealed no significant effects, all effects and interactions being
594 eliminated. This fails to provide evidence that the measured acoustic characteristics
595 influenced infants' orientation times for vMPs or cMPs.

596 **Lexical predictors of orientation time.** The 27 11-month-old infants for whom
597 vocabulary questionnaires were returned at 11 months knew on average 61.67 words (SD =
598 71.25) at this age, with an average of 51.26 unique consonant tiers (SD = 54.10) and 34.89
599 unique vowel tiers (SD = 30.32). The proportion of unique consonant tiers (M = 0.89; SD
600 = 0.07) was significantly greater than the proportion of unique vowel tiers (M = 0.70; SD
601 = 0.15), $t(24) = 9.56$, $p < .001$.

602 To assess the influence of lexical factors at 11 months, derived from vocabulary
603 scores, on orientation behavior, a linear mixed effects model was computed and analyzed
604 using the same procedure as Experiment 1. The resulting best fitting model is interpreted
605 here and a table of these results can be found in Appendix D (Table D3).

606 The resulting best fitting model included the effects of Cprop ($\chi^2(1) = 5.66$, $p = .02$)
607 and Vprop ($\chi^2(1) = 4.48$, $p = .03$) which were both significant, showing that *LogOT* was
608 longer for infants with a lower proportion of unique consonant tiers ($\beta = -4.02$, SE = 1.53)
609 but a higher proportion of unique vowel tiers ($\beta = 1.68$, SE = 0.75). Similar to Experiment
610 1, the lack of an interaction between any of the measured lexical factors and Type fails to

611 provide evidence that the measured lexical factors influenced infants' orientation times for
612 vMPs or cMPs.

613 **Relationship between CV preference and later vocabulary.** To examine the
614 relationship between infants' preference for vMPs or cMPs and the growth of word
615 production at 11, 13, 16, and 24 months, a linear mixed effects model was computed and
616 analyzed using the same procedure as Experiment 1. The resulting best fitting model is
617 interpreted here and a table of these results can be found in Appendix D (Table D4). Only
618 effects of *OT.diff* or interactions with *OT.diff* will be interpreted.

619 Figure 2 depicts word production with model fits for the effect of *OT.diff* at each age
620 measured. The results of the model revealed a significant interaction between *OT.diff* and
621 Age ($\beta = -0.01$, $SE = 0$, $p = .03$), indicating that children who had a negative *OT.diff*
622 (vMP preference) at 11 months had a greater increase in productive vocabulary over the
623 ages of 11, 13, 16, and 24 months. A summary of the vocabulary scores for infants with a
624 positive *OT.diff* score (cMP preference) and a negative *OT.diff* score (vMP preference) are
625 given in Table 1.

626 (Insert Figure 2 about here)

627 Discussion

628 Experiment 2 tested 11-month-old infants on their orientation times for consonant
629 (cMP) and vowel (vMP) mispronunciations of their own-name. Overall, infants had longer
630 log-transformed orientation times (LogOT) to consonant compared to vowel
631 mispronunciations, especially at the beginning of the experiment, showing a different
632 pattern of results than the 5- and 8-month-olds in Experiment 1. Considering the existing
633 evidence showing that French-learning infants initially exhibit a vowel bias at 5/6 months
634 and only later at 8- or 11-months does a consonant bias emerge (Bouchon et al., 2015;
635 Nishibayashi & Nazzi, 2016; Poltrock & Nazzi, 2015), it is unlikely that the pattern of

662 indication that under the conditions of the current study, infants attend longer to the
663 mispronunciation that contains a more novel change.

664 There are several possible explanations for why our task elicits longer looks to a
665 mispronunciation that contains a more novel change, whereas previously infants have been
666 found to attend longer to stimuli that are more similar to familiar words. According to
667 Hunter and Ames (1988), this pattern of looking preference is found when the difficulty of
668 the task is low or familiarization times are longer. Task difficulty in our study was
669 arguably high, as infants were tested on mispronounced word forms that differed minimally
670 from their correct pronunciation as well as from one another. This would set our task
671 difficulty as similar to that of other studies that have used a conflict task (Nishibayashi &
672 Nazzi, 2016; Poltrock & Nazzi, 2015). Instead, the greater difference between our study
673 and previous studies was the inclusion of a familiarization phase. Our study has arguably
674 longer familiarization times than previous studies, which either contained no familiarization
675 (Bouchon et al., 2015; Poltrock & Nazzi, 2015) or presented the target word embedded in a
676 familiarization passage (Nishibayashi & Nazzi, 2016). We argue that infants in our study
677 attended longer to mispronunciations containing a more novel change because we included
678 a familiarization phase that presented infants with the correct pronunciation of their name.

679 These results support evidence for consonant bias emergence between 5/6 months
680 (Bouchon et al., 2015; Nishibayashi & Nazzi, 2016) and 11 months (Poltrock & Nazzi,
681 2015) in French-learning infants. Results differ, however, in the timing of the switch from a
682 vowel to a consonant bias. Whereas our results suggest that a vowel bias is maintained at 8
683 months, studies investigating segmentation abilities have found a consonant bias at 8
684 months (Nishibayashi & Nazzi, 2016; Von Holzen et al., 2018). We examined word form
685 recognition, which requires the infants to access an existing representation, whereas word
686 segmentation tasks (Nishibayashi & Nazzi, 2016) require the infant to build a
687 representation for the newly segmented word form during the experiment. Sensitivity to
688 the phonological form of newly segmented words requires short-term retention whereas

689 own-name recognition tested in the current study requires infants to access an existing
690 word form representation in long-term memory. The difference in timing of the vowel to
691 consonant bias shift for unfamiliar (Nishibayashi & Nazzi, 2016) and familiar (present
692 study; Bouchon et al., 2015; Poltrock & Nazzi, 2015) word forms may therefore be due to
693 differences in the cognitive processes involved in familiar word form recognition and
694 unfamiliar word form segmentation. The representation or processing of the infant's own
695 name may be more resistant to the emergence of the consonant bias, which could be due to
696 the specificity of recognition of familiar word form representations. This could also be due
697 to early establishment of the word form at a younger age when vowel information played a
698 greater role in lexical processing, a vowel bias. Future research will have to determine
699 whether this delayed switch extends to other early familiar names, or is specific to the
700 infant's own name, which is highly frequent, uttered in many different situations, arguably
701 produced with widely varying intonation and pronunciation, and probably one of the first
702 words learned.

703 **Factors modulating the consonant bias: testing the acoustic and lexical** 704 **hypotheses**

705 Our second goal was to examine the role of different factors in consonant bias
706 emergence. We found no evidence for an influence of acoustic or lexical factors on
707 orientation times for vowel and consonant mispronunciations. This runs counter to the
708 predictions of the acoustic/phonetic hypothesis (Floccia et al., 2014), which attribute
709 infants' early vowel bias to vowels greater saliency over consonants, and infants' later
710 consonant bias to consonants' greater categorical perception, as well as the lexical
711 hypothesis (Keidel et al., 2007), which attributes emergence of a consonant bias to
712 discovery that consonants are more informative than vowels in lexical processing.

713 Bouchon et al. (2015) found that infants' vowel bias at 5 months was driven by
714 spectral distance differences between the individual correct and mispronounced vowel

715 stimuli presented to infants during the experiment. In a direct replication of this study
716 with British-English-learning infants, Delle Luche et al. (2016) found no evidence for a
717 consonant or vowel bias and weak evidence that infants' processing of consonants and
718 vowels is driven by acoustic cues, specifically energy information in consonants. Taken
719 together with the results of the current study, we suggest that the inconsistent findings in
720 terms of the role of acoustic/phonetic factors may result from the type of stimuli used. In
721 own-name recognition studies, the acoustic properties of correct pronunciations and
722 mispronunciations are not controlled for during recording (although the mispronounced
723 consonants and vowels are counterbalanced by feature type). For example, our lack of
724 replication of Bouchon et al's (2015) spectral property differences between consonant and
725 vowel mispronunciations might also partly explain why we did not find a link between
726 acoustic properties and orientation times for consonant and vowel mispronunciations in the
727 current study.

728 A complementary approach to studying the role of acoustic characteristics would be
729 to explicitly manipulate acoustic characteristics and the type of feature changed and then
730 measure the resulting influence on orientation times. To do so, it might be preferable to
731 use the same stimuli across infants, and thus other highly frequent and early recognized
732 words such as Mommy and Daddy (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999,
733 2012) rather than infants' own names. Note however that a relationship between
734 differential processing of consonants and vowels and acoustic factors might only be found
735 early in development, possibly only before the consonant bias is acquired, since there is
736 some evidence suggesting that consonants and vowels are differentially processed by adults
737 independently of their acoustic properties (Toro, Shukla, Nespors, & Endress, 2008).

738 Lexical factors were also not found to modulate orientation times to consonant and
739 vowel mispronunciations in 8- and 11-month-olds. This lack of evidence for a role of lexicon
740 size is congruent with previous evidence (Pollock & Nazzi, 2015; but see Mani & Plunkett,
741 2011). Yet, our analyses of the structure of the early lexicons of the infants of the present

742 study showed that in their early lexicons, there are more unique consonant than vowel
743 sequences (20.43 versus 15.57 respectively at 8 months; 51.26 versus 34.89 respectively at
744 11 months), which is one argument that has been invoked to link the emergence of the
745 consonant bias to early lexical acquisition. This finding has so far only been found in
746 normed French and Italian CDI data (Hochmann et al., 2011, Supplementary Material),
747 and is thus demonstrated here for the first time for individual infant data.

748 The null result for evidence of an influence of lexical factors may reflect a true lack of
749 effect, but may also be due to our measurement. Comprehension lexicon size and the
750 proportion of unique consonant and vowel tiers based on this measurement reflect what the
751 infant reportedly *knows*, not what they are *exposed* to. If the consonant bias emerges from
752 statistics computed on the input as opposed to comprehended words, then ours and
753 previous measurements (Hochmann et al., 2011; Poltrock & Nazzi, 2015) are insufficient to
754 capture this variation. Further investigation is needed to determine whether this is the
755 appropriate metric to assess the statistical structure of the early lexicon, which is proposed
756 by the lexical hypothesis to support emergence of the consonant bias (Keidel et al., 2007).

757 Poltrock and Nazzi (2015) proposed that instead of a strict division between the
758 acoustic-phonetic and lexical hypotheses, both may play a role in consonant bias emergence
759 (see also Nazzi et al. (2016)). Development of speech perception and word learning skills
760 occur at the same time and likely influence one another (Werker, 2018). Infants must first
761 have some knowledge that consonants and vowels are distinct phonological categories and
762 different from one another, which likely would emerge from their acoustic-phonetic
763 properties. Yet, this experience comes with exposure to word forms that contrast on these
764 properties and therefore on the distribution of consonants and vowels in an infant's first
765 words. Studying the influence of acoustic-phonetic and lexical factors simultaneously using
766 the approaches proposed above will hopefully clarify this issue.

767 Consonant bias and later vocabulary outcome

768 Although there was no evidence of a relationship at 8-months, a consonant bias at 11
769 months resulted in a relative disadvantage in productive vocabulary at 24 months
770 compared to infants that showed a vowel bias at 11 months. This runs counter to our
771 predictions that a greater consonant bias at 8 or 11 months would predict greater
772 productive vocabulary growth over the second year of life. Considering that studies with
773 adult speakers of a variety of languages have shown consistent evidence for a consonant
774 bias (Nazzi & Cutler, 2018; but see studies with tonal languages, Gómez et al., 2018;
775 Poltrock et al., 2018; Wiener & Turnbull, 2016), we had predicted that infants that exhibit
776 early consonant bias emergence may have an advantage in vocabulary acquisition because
777 consonants are more informative in the French lexicon (Hochmann et al., 2011; Keidel et
778 al., 2007). The only study to examine this relationship found that sensitivity to
779 mispronunciations in general, but not specifically consonant or vowel changes, predicted
780 overall vocabulary growth at 24 months of age (Von Holzen et al., 2018). Thus, the
781 evidence to-date suggests that a vowel preference or sensitivity to phonological alterations
782 in general is beneficial to vocabulary growth. This stands in contrast to our predictions,
783 but we emphasize that sensitivity to both consonant and vowel information is essential to
784 successfully acquiring a native language. We note that the current study as well as that of
785 Von Holzen et al. (2018) measured later outcomes in productive vocabulary as opposed to
786 comprehension, because this was the only measure available at all four ages. There was
787 little variation in the few words produced by infants in the early ages measured (8/11 and
788 13 months), as infants produce few words at these ages. If more measurements are made at
789 younger ages and comprehension as opposed to production is measured, an initial instead
790 of long term advantage in acquisition may be uncovered.

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Table 1

A summary of the number of vocabulary questionnaires returned and words comprehended and produced by 8-month-olds (Experiment 1) and 11-month-olds (Experiment 2) at each age measured. Note that vocabulary questionnaires were not collected for the 5-month-olds tested in Experiment 1.

Age	Age Measured	n	Comprehension			Production		
			Mean	SD	Range	Mean	SD	Range
8	8	21	22.9	35.09	0 - 122	1.19	4.04	0 - 19
	13	22	68.91	59.5	0 - 181	5.41	13.69	0 - 66
	16	19				11.47	11.34	0 - 39
	24	20				177.45	108.86	0 - 375
11	11	27	61.67	70.08	0 - 282	2.19	3.32	0 - 11
	13	25	70.71	67.67	0 - 309	3.80	5.37	0 - 19
	16	23				42.83	102.86	0 - 511
	24	25				239.72	173.99	4 - 618

Table 2

A summary of the means and standard deviations of the intensity and duration measurements, as well as the normalized difference scores for intensity, duration, and spectral measurements for correct pronunciations (CP) and mispronunciations (MP) presented to 5- and 8-month-olds (Experiment 1) and 11-month-olds (Experiment 2).

Exp.	Acoustic	Vowels			Consonants		
		Mean (SD)		Difference	Mean (SD)		Difference
		CP	MP		CP	MP	
1	Duration	85.08 (27.35)	86.67 (30.08)	-0.03 (0.21)	65.97 (21.19)	73.2 (27.39)	-0.16 (0.43)
	Intensity	69.91 (6.79)	70.34 (5.02)	-0.01 (0.06)	53.75 (8.37)	53.76 (7.63)	-0.01 (0.16)
	Spectral				1.64 (0.24)		
2	Duration	91.62 (48.28)	99.83 (42.32)	-0.2 (0.34)	65.72 (18.03)	64.19 (25.41)	0.01 (0.29)
	Intensity	69.63 (7.63)	69.76 (5.93)	-0.01 (0.06)	57.02 (8.61)	55.19 (9.09)	0.03 (0.11)
	Spectral				1.72 (0.39)		

Table 3

A summary of the number of questionnaires returned and mean words produced at each age measured for 8- (Experiment 1) and 11-month-old (Experiment 2) infants with either longer orientation times (preference) for consonant (cMP) or vowel mispronunciations (vMP).

Age	AgeMeasured	cMP preference			vMP preference		
		n	M	SD	n	M	SD
8	8	8	2.88	6.56	13	0.15	0.55
	13	8	11.88	22.33	14	1.71	2.49
	16	8	14.62	12.58	11	9.18	10.88
	24	7	175.71	128.11	13	178.38	106.86
11	11	15	2.27	3.97	12	2.08	2.61
	13	13	3.38	5.64	12	4.25	5.48
	16	12	65.83	142.71	11	17.73	21.71
	24	14	217.07	179.49	11	268.55	178.29

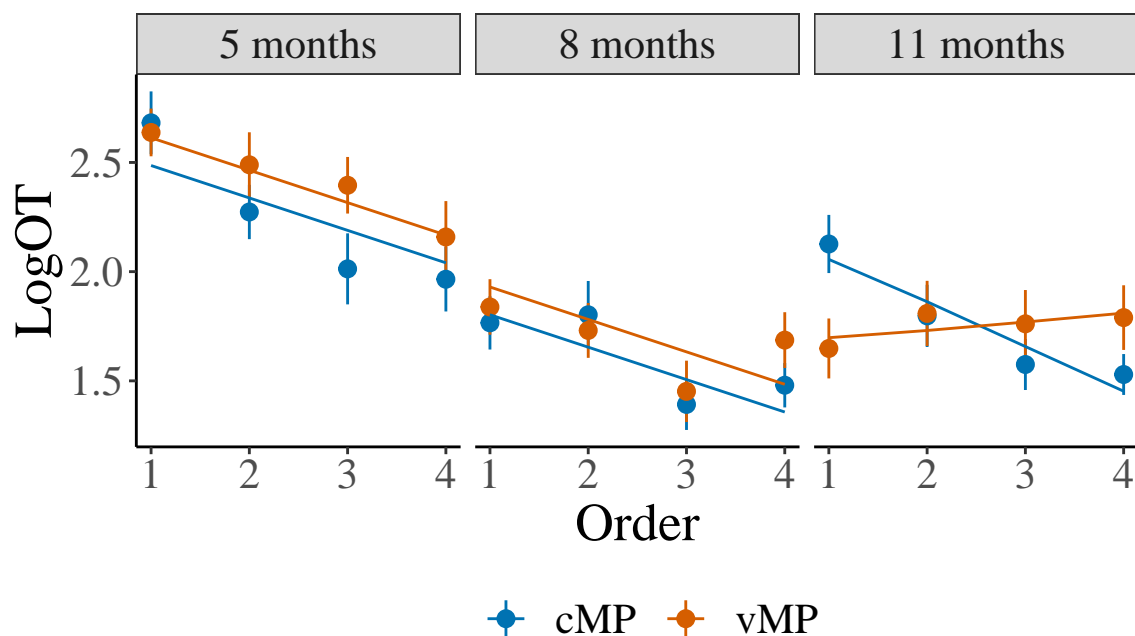


Figure 1. The mean and SE range of log-transformed orientation times (LogOT) is plotted against Order separately with model fits from Experiment 1 for 5-month-olds (left panel) and 8-month-olds (middle panel) and Experiment 2 for 11-month-olds (left panel). The color blue indicates consonant mispronunciations (cMPs) and orange indicates vowel mispronunciations (vMPs).

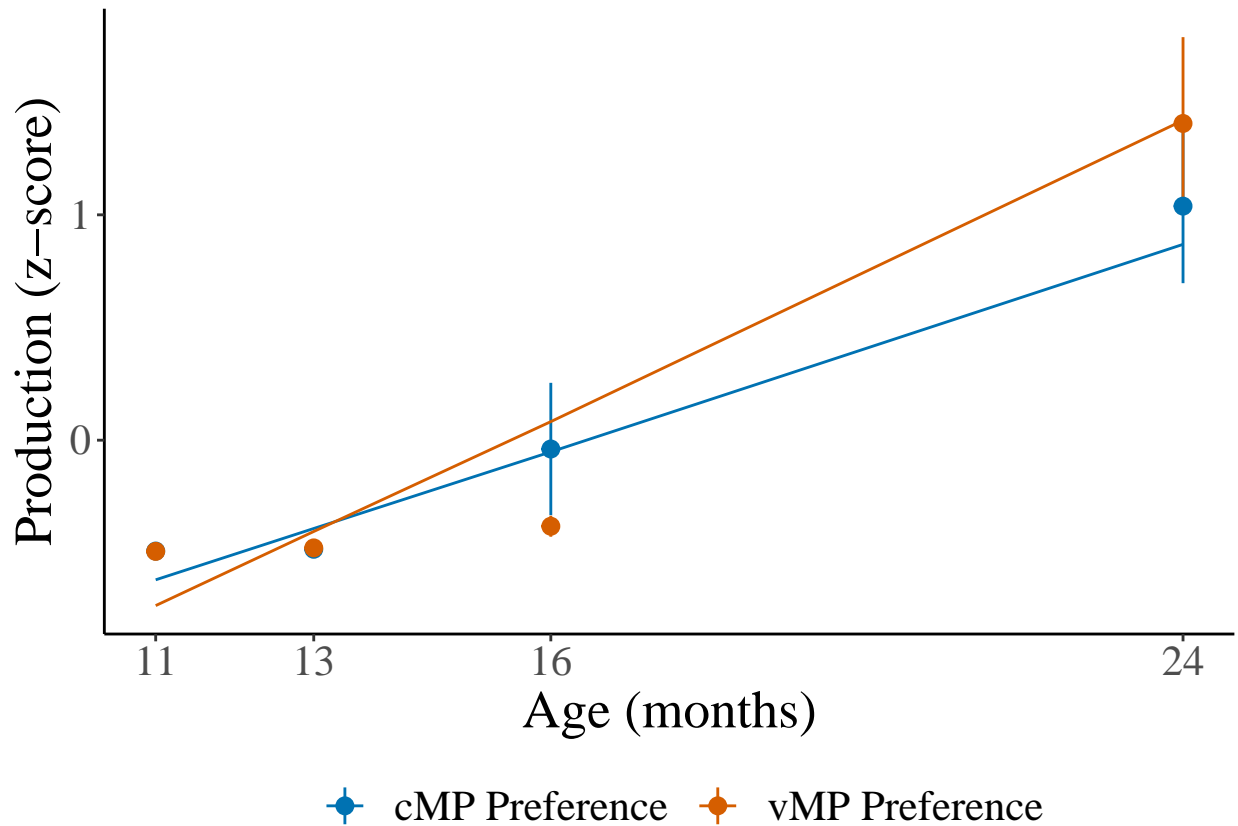


Figure 2. Total word production (z-score) for the 11-month-olds tested in Experiment 2 at the four ages measures (11, 13, 16, 24 months) for infants with either longer orientation times for vowel (vMP preference) or consonant mispronunciations (cMP preference). Lines indicate the fit of the model and whiskers indicate a standard error of 1