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# Vowel Harmony Preferences in Infants Growing up in Multilingual Ghana (Africa)

Paul Okyere Omane[1, 2, 3, 4, 5, 6], Titia Benders[7, 8], and Natalie Boll-Avetisyan[1]
[1] Department of Linguistics, Research Focus Cognitive Sciences, University of Potsdam
[2] School of Psychological Sciences, Macquarie University
[3] International Doctorate for Experimental Approaches to Language and Brain, Speech and Language Sciences, Newcastle University
[4] International Doctorate for Experimental Approaches to Language and Brain, School of Psychological Sciences, Macquarie University
[5] Department of Linguistics, International Doctorate for Experimental Approaches to Language and Brain, University of Potsdam
[6] International Doctorate for Experimental Approaches to Language and Brain, Center for Language and Cognition Groningen, University of Groningen
[7] Amsterdam Center for Language and Communication, University of Amsterdam
[8] Department of Linguistics, Center for Language Sciences, Macquarie University

Infants' preference for vowel harmony (VH, a phonotactic constraint that requires vowels in a word to be featurally similar) is thought to be language-specific: Monolingual infants learning VH languages show a listening preference for VH patterns by 6 months of age, while those learning non-VH languages do not (Gonzalez-Gomez et al., 2019; Van Kampen et al., 2008). We investigated sensitivity to advanced tongue root (ATR) harmony in Akan (Kwa, Niger-Congo) in 40 six-month-old multilingual infants (21 girls) in Ghana, West Africa (an understudied population), all learning Akan, Ghanaian English, and most of them several other understudied African languages (e.g., Ga, Ewe). We hypothesized that infants learning both ATR harmony and nonharmony languages would demonstrate sensitivity to ATR harmony. Using the central fixation procedure, infants were presented with disyllabic nonwords that were either harmonic (e.g., puti) or nonharmonic (e.g., petɔ) based on their ATR features. Infants demonstrated sensitivity to ATR harmony with a familiarity preference, listening longer to harmonic syllable sequences than nonharmonic ones. The relative amount of exposure to (an) ATR harmony language(s) did not modulate the preference. These results shed light on our understanding of early multilingualism: they suggest that early sensitivity to VH in multilinguals may be similar to monolingual infants learning other types of VH, irrespective of simultaneous experience with non-VH languages. We conclude with reflections on studying infant language acquisition in multilingual Africa.

***Public Significance Statement***
The public significance of this study is to understand how learning multiple languages in Africa may affect infants' speech perception.

*Keywords:* infant speech perception, multilingualism, advanced tongue root harmony, field-based psycholinguistic

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Most research on infant and child language development has focused on populations growing up in Western cultures with Indo-European languages. As this can cause biases in theory building, there is a growing call among language acquisition researchers and developmental psychologists for more diversity across languages and cultures studied (e.g., Aravena-Bravo et al., 2023; Cristia et al., 2023; Kidd & Garcia, 2022; Singh et al., 2023). Across the world, infants' early language and cultural experiences may, for example, vary

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Paul Okyere Omane https://orcid.org/0000-0002-0859-9826
Titia Benders https://orcid.org/0000-0003-0143-2182
Natalie Boll-Avetisyan https://orcid.org/0000-0001-5446-946X
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*continued*

significantly concerning the number of languages they are immersed in. Moreover, languages differ in their phonology, morphology, and syntax. In line with the call for diversification, the present study focuses on infants growing up multilingually in Ghana, West Africa (an understudied population), with several understudied African languages (e.g., Akan, Ewe, and Ga). Some of these languages adhere to vowel harmony (VH), a phonological rule attested in many languages worldwide that requires vowels within words to have similar features. For the present study, using a mobile lab in Accra, Ghana's capital, we experimentally investigated whether multilingual infants exposed to (a) VH languages alongside non-VH languages are sensitive to VH and (b) whether this sensitivity is modulated by the relative amount of exposure to VH language(s).

VH is a language-specific phonotactic constraint on the co-occurrence of vowels in a word that requires vowels to share a specific phonetic feature. For example, in Finnish, front vowels (e.g., /æ/,/ø/,/y/) do not combine with back vowels (e.g., /a/,/o/,/u/) in the same word. Thus, while words like näkö "sight" and maku "taste" are allowed, "möku" is not a possible word in the language because it contains both front and back vowels, in violation of the VH constraint in Finnish. While not all languages show VH (e.g., English, an Indo-European language, and Ga, a Niger-Congo language), it is attested in many locally and genetically unrelated languages (for a review, see Rose & Walker, 2011), such as Finnish (Finno-Ugric language), Akan, Dagbanli (Niger-Congo language), and Turkish (Altaic language). VH is not only present in the lexicon of these (and many other) languages; speakers of these languages also use it for speech processing, such as speech segmentation (see Kabak et al., 2010; Suomi et al., 1997; Vroomen et al., 1998). Moreover, speakers of non-VH languages can learn harmony rules in artificial language experiments more easily than rules that are less natural but of comparable complexity (e.g., Finley & Badecker, 2009a, 2009b; Martin & Peperkamp, 2020; Moreton, 2008), suggesting that VH could be language-specific, but still be based on universal innate or perceptual biases (see Moreton, 2008, for an informative discussion).

Since language-specific speech perception is developed in infancy, and infants, in particular, may display learning biases, it is important to study VH perception in infants. Studies undertaken so far provide evidence that infants show language-specific phonotactic biases in processing VH information from 6 months of age onward: they prefer listening to vowel-harmonic over vowel-disharmonic syllable sequences if their native language displays the VH under test (Turkish: Altan et al., 2016; Hohenberger et al., 2016, 2017; Van Kampen et al., 2008; Hungarian: Gonzalez-Gomez et al., 2019), but not when their language has no VH (French: Gonzalez-Gomez et al., 2019; Germany: Van Kampen et al., 2008). These studies have, so far, mostly looked at monolingually raised infants, except the Turkish-learning infants in Van Kampen et al. (2008), who were from families in which (mainly) Turkish was spoken but who were also exposed to about 2.4 hr of German per day. Moreover, these studies only addressed vowel backness and rounding harmony in two languages (Turkish and Hungarian).

To this point, very little is known about the development of phonotactic knowledge in bilingual or multilingual infants and how language exposure affects their speech perception. So far, only one study by Sebastián-Gallés and Bosch (2002) has investigated 10-month-old Catalan–Spanish bilingual infants' perceptual preferences of final consonant clusters (e.g., /-rt/ and /-sk/ in words like birt and mosk, respectively) that were attested only in one of their native languages (Catalan). Results showed that infants prefer legal over illegal clusters, but the results do not allow for strong conclusions about the effects of multiple language exposure on phonotactic processing, given the absence of a significant interaction of cluster type (legal vs. illegal) with bilingual dominance (Catalan-dominant and Spanish-dominant). Similarly, no evidence for a role for exposure or dominance has been found in word segmentation (Orena & Polka, 2019; Polka et al., 2017). However, in other domains of speech perception, language input/dominance has been found to modulate infants' sensitivity to rhythm patterns (Molnar et al., 2014), while results are mixed on phoneme processing (Bosch & Sebastián-Gallés, 2003; Liu & Kager, 2015; Ramon-Casas et al., 2009) and word stress pattern discrimination and preference (Abboub et al., 2015; Bijeljac-Babic et al., 2012, 2016). The current state of the literature on infants learning multiple languages shows that more research is needed on the development of phonotactics in multilingual infants to better understand how bilingualism or multilingualism affects how infants process phonotactic information in their ambient languages.

The present study investigates (a) how multilingual infants with simultaneous exposure to both VH and non-VH languages process VH and (b) whether infants' processing is related to their exposure to VH languages. We specifically investigated infants learning (an) advanced tongue root (ATR) harmony language (or languages; e.g., Akan) spoken in Ghana. In this study, we use the term "exposure" to refer to the relative amount of exposure to ATR harmony language(s) and the presence of (an) ATR harmony language(s) in the child's input. In ATR harmony languages, vowels are grouped into two sets based on their tongue root feature: vowels are articulated either with the base of the tongue moved forward/advanced (+ATR, e.g., /i, e, u, o/) or moved backward/retracted (−ATR, e.g., /ɛ, ʊ, ɔ, ɪ/). In Akan (as in many other ATR harmony languages in Ghana, e.g., Dagbanli, Anum, Dagaare), words must (with few exceptions) contain either

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Correspondence concerning this article should be addressed to Paul Okyere Omane, Department of Linguistics, Research Focus Cognitive Sciences, University of Potsdam, Karl-Liebknecht-Straße 24–25, 14476 Potsdam, Germany. Email: omaneokyere@hotmail.com

only (+ATR) vowels (e.g., Akan: /kukuo/ "pot,"/efie/ "house") or only (−ATR) vowels (e.g., Akan: /ɛmʊ/ "rice,"/ɛwʊɔ/ "honey"). Affixes must also agree in ATR with the vowel(s) of the stem they are attached to (e.g., Akan:/ /o-di/ "s/he eats,"/ɔ-tɪ/ "s/he lives at"; for more information, see Dolphyne, 1988; Hess, 1992; Kügler, 2015). ATR harmony is, therefore, an essential part of developing native language phonotactics for many infants growing up in Ghana and in other places in Africa, as many African languages have ATR harmony (see Casali, 2003, 2008; Rose, 2018).

The language situation in Ghana makes it possible and, in fact, essential to study infants growing up with different languages: Ghana is a highly multilingual nation with about 83 living languages (Eberhard et al., 2023). Most Ghanaians speak at least two and often more languages, Ghanaian English and (an) additional local language(s) or two or more local languages (Bodomo et al., 2010). Based on the first author's observations, infants growing up in Ghana are exposed to two or more languages simultaneously from birth by their parents and other family members, such as grandparents, uncles, and aunts, who may use different languages as their preferred one. Some infants are born into a compound house where the people speak different ethnic languages that infants, because of shared caretaking practices, are exposed to from birth (see Omane, Benders, Duah, & Boll-Avetisyan, 2023, for a description of how infants are raised multilingually in Ghana). Some of these languages have VH (besides Akan, the most common indigenous language in Ghana, e.g., Anum, Dagaare, and Dagbanli), while others do not (e.g., Ga, Ewe, and Ghanaian English). Given the language situation, Ghanaian infants usually simultaneously learn both VH and non-VH languages from birth.

In the present study, we investigated multilingual infants' sensitivity to VH and whether sensitivity to ATR harmony also emerges early in infancy, as observed for other types of VH. As an indicator of their sensitivity, we measured infants' listening preferences as indicated by their looking times (LTs) using the central fixation procedure (Cooper & Aslin, 1990). We addressed two research questions. The first question is do infants learning an ATR harmony language (e.g., Akan) alongside other non-VH languages show sensitivity to ATR harmony in Akan? Following this question, our main hypothesis was that infants would demonstrate sensitivity to ATR harmony based on their experience with it in their language input. This hypothesis could be confirmed by one of two result patterns: either infants show a harmony preference (which would be interpreted as a familiarity preference for harmony reflecting their experience with ATR harmony in their language input) or a nonharmony preference (which would be interpreted as a novelty preference), as the direction of the preference could go either way and would still indicate sensitivity (see Bergmann et al., 2019; Houston-Price & Nakai, 2004). Given the age we tested (6 months), in light of background studies (see Altan et al., 2016; Hohenberger et al., 2016, 2017), a familiarity preference is more likely. Second, we asked whether the relative amount of exposure to (an) ATR harmony language (or languages; e.g., Akan, Anum) would or would not modulate sensitivity to ATR harmony. If the difference in LTs to harmonic versus nonharmonic syllable sequences is more enhanced the more infants are exposed to (an) ATR harmony language(s), we can conclude that the relative amount of exposure to (an) ATR harmony language(s) modulates the sensitivity to ATR harmony. If LTs to harmonic and nonharmonic syllable sequences do not differ depending on relative exposure to (an) ATR harmony language(s), we cannot conclude that. Note that, in principle, effects of ATR harmony sensitivity and exposure could be complementary: All infants might show a listening preference for one of the two patterns (harmonic, nonharmonic), and on top of this, the more infants experience ATR harmonic language input, the more enhanced that preference might be.

# Method

## Participants

We preregistered a sample size of 40 infants and met this target. Forty 6-month-old infants (21 girls, $M_{age}$ = 6 months 2 days; range = 6.00–6.09) participated in this study. This target sample size was determined based on previous phonotactic studies, where between 24 to 40 infants (per group) are commonly tested (e.g., VH studies; Gonzalez-Gomez et al., 2019; Van Kampen et al., 2008), and also, per our calculation, 40 infants were the maximum sample we could reach in 6 months of a fieldwork stay. An additional 11 infants were tested but excluded from the analyses due to parent interference during the experiment ($n$ = 4), experimenter error ($n$ = 2), or the infant being born preterm (i.e., before 37 weeks of gestation, $n$ = 5). Infants were recruited through personal networks (snowball sampling) and from two hospitals in Accra (the University of Ghana Hospital in Legon and a hospital that prefers to be anonymous). All infants were raised multilingually in Ghana. The recruitment criterion was for infants to be exposed to at least Akan (with ATR harmony) and at least one non-VH language (e.g., Ga, Ewe, Ghanaian English). A parental questionnaire and a diary logbook were used to assess the linguistic background of the infants in our sample (see the Procedure section below). The data showed that infants were exposed to two to five languages (42.5% two languages, 45% three languages, 10% four languages, and 2.5% five languages); see Table 1 for the language combinations. We obtained informed consent from caregivers before participating in the study. No infant was reported to have any neurocognitive or genetic disorders. Participants received a fee compensating for their participation. The study was approved by the Ethics Committee for Humanities at the University of Ghana (Ghana) under the project name Multilingual Infants' Use of VH for speech perception in Akan (approval number: ECH 226/21-22).

## Transparency and Openness

This study's design, hypothesis, and analysis were preregistered on the Open Science Framework available at https://doi.org/10.17605/OSF.IO/9M3Z4. The data, study materials, and analysis

**Table 1**

*Language Combinations Across Infants as Obtained From the Questionnaire, Organized With Two and Three Languages on the Left and Four and Five Languages on the Right*

| Language combination | % | Language combination | % |
|---|---|---|---|
| Two languages | | Four languages | |
| Akan, GhE | 42.5 | Akan, GhE, Ewe, Ga | 5 |
| Three languages | | Akan, GhE, Ewe, French | 2.5 |
| Akan, GhE, Ga | 27.5 | Akan, GhE, Ga, Krobo | 2.5 |
| Akan, GhE, Ewe | 10 | Five languages | |
| Akan, GhE, Krobo | 5 | Akan, GhE, Ewe, Ga, Krobo | 2.5 |
| Akan, GhE, Basari | 2.5 | | |

*Note.* GhE = Ghanaian English.

code will be publicly available on the project Open Science Framework page available at https://doi.org/10.17605/OSF.IO/964VF.

## Materials

### Task Design

Our experimental implementation closely followed that of previous VH studies. For trial composition (i.e., a combination of different tokens of the same nonword), our design followed that of Van Kampen et al. (2008) and Experiment 2 of Altan et al. (2016). In terms of the number of trials per stimulus type, we presented infants with 12 trials (similar to Ota & Skarabela, 2018, who also used the central fixation procedure as we did) rather than fewer (eight: Van Kampen et al., 2008; four: Altan et al., 2016) or more trials (sixteen: Gonzalez-Gomez et al., 2019) as used in previous head-turn preference studies on VH.

### Auditory Stimuli

Sixteen bisyllabic consonant-vowel-consonant-vowel (CVCV) nonwords (eight vowel harmonic, henceforth harmonic, and eight not-vowel harmonic, henceforth nonharmonic) were created from the Akan phoneme inventory[1] (see Dolphyne, 1988). Eight vowels, that is, four pairs of an ATR vowel (+ATR) with an unadvanced tongue root vowel (−ATR) of the same height (considering the broad categories: high, mid, and low), rounding, and backness, were selected from the Akan vowel inventory (see Table 2). Only two Akan vowels—the low vowels /a/ and /æ/—were not used in creating the stimuli since they can violate the Akan ATR harmony rule (Dolphyne, 1988). Akan does not have lexical stress (Dolphyne, 1988); hence, the stimuli were recorded without a specific stress pattern. However, with Akan being a tone language, we recorded the stimuli with a high–low tone pattern.

Sixteen two-vowel templates (eight harmonic and eight nonharmonic) were created from the selected vowels. Vowels in each template always shared (broad) vowel height (e.g., /_i_u/ are both high vowels; /_ɔ_e/ are both midvowels—disregarding the difference between midlow and midhigh). The distribution of ATR features across the first and second vowels was balanced across templates, with (a) eight harmonic templates: four with only (+ATR) vowels (e.g., [_i_u]) and four with only (−ATR) vowels (e.g., [_ɪ_ʊ]) and (b) eight nonharmonic templates: four with a (+ATR −ATR) sequence (e.g., [_e_ ɔ]) and four with a (−ATR +ATR) sequence (e.g., [_ɔ _ e]). See the full list of vowel templates in Table 3.

Four stop consonants (p, b, t, d) from the Akan consonant inventory were used to create the stimuli. These consonants were evenly distributed on voicing (two voiced /b, d/ and two voiceless /p, t/) and place of articulation (two labial /b, p/ and two coronal /d, t/). They were inserted as onset consonants into the vowel templates to create the 16 (harmonic and nonharmonic) bisyllabic CVCV nonwords in Table 4. Two constraints, based on voicing and place of articulation, determined which consonants were placed in which slots: (1) The onset of the first syllable was always the bilabial plosive (/p/ or /b/), while the second syllable started with a coronal (/t/ or /d/). This was motivated by the labial–coronal bias observed in infants (Nazzi et al., 2009). (2) The two consonants in each word shared the same voicing feature (either both voiced or both voiceless; see Table 4). Six native speakers of each language, Akan, Ewe, Ghanaian English, and Ga, confirmed that all 16 resulting CVCV items are nonwords in the respective languages.

The audio stimuli were recorded by a linguistically trained female multilingual speaker of Ewe, Akan, Ghanaian English, and Ga with a native accent (as judged by the speaker herself) in all these languages. The speaker acquired Ewe, Akan, and Ghanaian English from birth and Ga from about 7 years of age. We selected a multilingual who speaks both languages with (Akan) and without harmony (Ga, Ewe, and Ghanaian English), as producing nonharmonic nonwords would have been difficult for a speaker of only languages with ATR harmony. The speaker was asked to produce all target CVCV nonwords with a high–low tone pattern. The target bisyllabic CVCV nonwords were embedded in various sentence types to facilitate the realization of acoustic variability between the tokens: (a) declarative: yɛfrɛ no puti; "s/he is called puti"; (b) interrogative: wonim puti? "Do you know puti"? and (c) imperative: Fa puti! "Take puti!." The speaker read the sentences in Akan in an infant-directed manner. Thirty tokens of each nonword were recorded. The recording session was supervised by the first and last authors of this study (the first author spoke Akan with the speaker during the session). The recording took place in a soundproof booth at the University of Potsdam, using the Audacity software and a standing microphone placed about 30 cm away from the speaker's mouth.

For each nonword, eight recorded tokens were selected that were (a) produced with the target high–low tone pattern and (b) produced with modal voice. Next, we composed trials that consisted of 12 tokens of the same nonword (the eight tokens followed by four additional ones, randomly drawn from the original eight). All trials were created to have a total duration of 14 s; for this, interstimulus interval ranged between 489 and 650 ms. See Table 5 for acoustic measurements of harmonic and nonharmonic trials.

### Visual Stimuli

There were two visual stimuli: a rotating colorful wheel that served as an attention-getter before the presentation of each trial and a static colorful checkerboard that was used as an unrelated visual attractor while an auditory stimulus was being played.

### Procedure

#### *Experiment*

We used the central fixation procedure (Cooper & Aslin, 1990). Each infant was tested individually in a mobile lab that was set up in one of the three locations: a room at the Department of Linguistics at the University of Ghana or one of the two hospitals. To minimize the influence of the experimenter during testing, the rooms were partitioned into two with a curtain so that the infants and their caregivers were on one side and the experimenter was on the other side. Infants were seated on their caregivers' laps in front of a 17.3-inch Asus ROG Strix XG17 monitor at about 40–50 cm away. Two Logitech z120 Principal Component (PC) speakers for the auditory stimuli presentation were placed below the extreme bottom left and right corners of the screen. The experimenter observed and

[1] Akan has nine distinct oral (/I, e, ɛ, a, ɔ, o, u, ɪ, ʊ/) and five nasalized (/ĩ, Ĩ, ã, ʊ̃, ũ/) vowels, but only seven vowels (/i, e, ɛ, a, ɔ, o, u/) are represented in the orthography (Dolphyne, 1988).

**Table 2**
*The Set of +ATR Vowels and Their −ATR Counterparts Used in Creating the Stimuli With Their Standard Phonetic Description*

| +ATR vowels | Standard phonetic description | −ATR vowels | Standard phonetic description |
|---|---|---|---|
| i | High front unrounded | ɪ | Semihigh front unrounded |
| u | High back rounded | ʊ | Semihigh back rounded |
| e | Midhigh front unrounded | ɛ | Midlow front unrounded |
| o | Midhigh back rounded | ɔ | Midlow back rounded |

*Note.* ATR = advanced tongue root.

recorded the infants' looking behavior through a webcam placed on top of the screen in front of the infants. The experimenter manually coded the infants' LTs during the experiment. The experiment was run in Habit2 stimulus presentation and data acquisition software for infant looking-time studies Version 2.2.1 (Oakes et al., 2019).

At the onset of each trial, the centrally positioned attention-getter appeared on the screen. Once the infants' attention was engaged, the static checkerboard appeared on the full screen. Every session started with one practice trial, a musical file (Mozart sonata), to acquaint the infants with the testing procedure. Subsequently, infants received 12 test trials in a pseudorandomized order (in blocks of four, there were always two harmonic and two nonharmonic nonwords; no four subsequent trials started with the same consonant). Each test trial ended after the maximum trial length of 14 s was reached or when the infant looked away from the screen for more than two consecutive seconds. The infants' behavior was measured by the accumulated length of time they looked at the screen when an auditory stimulus was being played.

### Questionnaire

A parental language background questionnaire was administered before the experiment (in order to check if infants meet the recruitment criteria of exposure to at least Akan as an ATR harmony language and at least one non-VH language, gestation age, and genetic disorders). The questionnaire served to obtain an estimate of the languages directed to the infants by a range of speakers (e.g., father, mother, grandparents, older sibling/s, other caregivers) or that the infants overhear in the environment (e.g., adult conversation, media, social/religious gathering). This questionnaire, which was administered in the form of an interview, was inspired by the Language Exposure Questionnaire for Infants (e.g., Bosch & Sebastián-Gallés, 1997, 2001; Byers-Heinlein et al., 2020) and extended to the multilingual Ghanaian context. The relative input to each language was calculated as the proportion of time an infant heard a given language over the total time of exposure to all languages across speech directed to the infant and overheard speech (for a description of how exposure was computed from the questionnaire, see Supplemental Material S1).

**Table 3**
*The Combination of Vowels in the Harmonic and Nonharmonic Vowel Templates Used in the Stimuli*

| Harmonic | | Nonharmonic | |
|---|---|---|---|
| +ATR | −ATR | +ATR −ATR | −ATR +ATR |
| _i_u | _ɪ_ʊ | _i_ʊ | _ɪ_u |
| _u_i | _ʊ_ɪ | _u_ɪ | _ʊ_i |
| _e_o | _ɛ_ɔ | _e_ɔ | _ɛ_o |
| _o_e | _ɔ_ɛ | _o_ɛ | _ɔ_e |

*Note.* ATR = advanced tongue root.

### Logbook

Besides the questionnaire, we used a logbook[2] method to estimate language exposure throughout the infants' entire day. With this method, caregivers were instructed to complete a logbook, that is, a small card placed in a vest worn by the baby at home. They were asked to indicate, by ticking different options, the different languages their infants heard every half an hour for an entire day between 7 a.m. and 7 p.m. while the baby was awake. The caregiver filled out the logbook a day or two after the experiment. Our logbook method is similar to the language diary (De Houwer & Bornstein, 2003; Place & Hoff, 2011) methods used in prior studies but more simplified. For example, while Place and Hoff (2011) gathered data over a period of 7 weeks, we limited our data collection to a single day. Unlike their comprehensive approach of asking parents to inform them about language input by multiple input-giving individuals and different potential contexts in which language input may occur, our focus was solely on the languages the child heard. This decision was made to avoid overburdening parents/caregivers. Given the multiple caregiver practices in Ghana and to facilitate clear instructions for different caregivers, we aimed to keep the logbook instructions maximally simple. We provided full instructions and a demonstration of how to complete the logbook after the experimental session. The experimenter picked up the logbook from the caregivers' homes (for most of the caregivers) or met them at the hospital after completion (for a description of how exposure was computed from the diary logbook, see Supplemental Material S2).

This study's design, hypothesis, and analysis were preregistered (see https://doi.org/10.17605/OSF.IO/9M3Z4). The data, study materials, stimuli, and analysis code are available in an online repository accessible at https://doi.org/10.17605/OSF.IO/964VF.

## Data Processing and Analyses

### Data Exclusion

Following previous studies (Bosch et al., 2013; Junge et al., 2020), we predetermined (before data collection) to exclude trials with a total LT of less than 1 s from the analyses. Four trials (two harmonic

[2] The logbook approach was inspired by Marisa Casillas in a personal conversation.

**Table 4**
*Target Harmonic and Nonharmonic Bisyllabic CVCV Nonwords Used in the Experiment*

| Harmonic | | Nonharmonic | |
|---|---|---|---|
| +ATR | −ATR | +ATR −ATR | −ATR +ATR |
| bidu | bɪdʊ | bidʊ | bɪdu |
| bode | bɔdɛ | bodɛ | bɔde |
| peto | petɔ | petɔ | peto |
| puti | pʊtɪ | putɪ | pʊti |

*Note*. CVCV = consonant-vowel-consonant-vowel; ATR = advanced tongue root.

and two nonharmonic) across three infants were not included in the analyses based on this exclusion criterion.

## *Preregistered Model*

The analyses were carried out with R (R Core Team, 2023). Analyses of the LT (accumulated looks on screen in seconds[s] per trial) as dependent variable were performed using linear mixed-effect modeling with the lme4 package (v1.1-26; Bates, Maechler, et al., 2015). Normality tests showed that the raw but not the log-transformed LTs data were normally distributed, so we proceeded with raw LTs as a dependent measure. Our preregistered model included the fixed effects of harmony (two levels: harmonic vs. nonharmonic) coded using a successive difference contrast coding (harmonic coded as −0.5; nonharmonic as 0.5), an orthogonal contrast (using the MASS package, Version 7.3-54, Venables & Ripley, 2002), amount of language exposure to (an) ATR harmony language (or languages; continuous variable, centered), age in days (continuous variable, centered), and trial number (within-participant factor, continuous variable, centered). With only 12 trials and 40 participants in our study, we treated trial number as a continuous predictor (and not as discrete, for example) to avoid using a high number of degrees of freedom, which could lead to overfitting the model and the potential reduction of the power of the analyses. The random structure included random intercepts for participant and item and a random by-participant slope of harmony. The preregistered R formula was:

$$\text{lmer}(\text{LT} \sim (\text{harmony}*(\text{LogbookC} + \text{questionnaireC} + \text{ageC} + \text{trialnumberC}) + (1 + \text{harmony}|\text{participant}) + (1|\text{item}), \text{data} = \text{data})). \quad (1)$$

For the case of convergence issues, we had preregistered to reduce the model and fit the most parsimonious model (Bates, Kliegl, et al., 2015). For our preregistered analysis, it was indicated that exposure to (an) ATR harmony language derived from both the logbook and the questionnaire would be entered into our model. However, we found the two measures to be correlated, $r(38) = .53$, $p < .001$; see Figure 1. Therefore, to reduce collinearity, we performed a principal components analysis with the questionnaire and logbook data. The first PC, which accounts for 77% of the variance of the combined measures, was used as a predictor (continuous variable, centered). Hence, the preregistered maximal model was changed to:

$$\text{lmer}(\text{LT} \sim (\text{harmony})*(\text{exposureC} + \text{ageC} + \text{trialnumberC}) + (1 + \text{harmony}|\text{participant}) + (1|\text{item}), \text{data} = \text{data}). \quad (2)$$

For the interested reader, the results of the originally preregistered model with both the questionnaire and logbook measures included as separate predictors (in place of the PC) are presented in the Supplemental Materials (see Supplemental Table S2a–S2c for the model formula and output). This model did not result in a better model fit than the model without any exposure predictor.

## *Model Checking and Model Building*

The preregistered model did not converge because of its complexity. Therefore, subsequently, the model was reduced. We did a model comparison by first removing the random intercept for item and then the random by-participant slope of harmony since their variances were estimated to be zero, which resulted in a singular fit warning. The resulting model showed a significant effect of harmony and trial number but no significant effect of exposure to (an) ATR harmony language(s) and no harmony and exposure interaction (see model formula and output in Supplemental Material Table S3). When reentering the random intercept for item, we found that the results of the fixed part were identical to that of the model without it. Hence, we report the model that includes the by-item random intercept as the best model for our data. The formula for this model was:

$$\text{LT} \sim (\text{harmony})*(\text{exposure} + \text{age} + \text{trialnumber}) + (1|\text{id}) + (1|\text{item}). \quad (3)$$

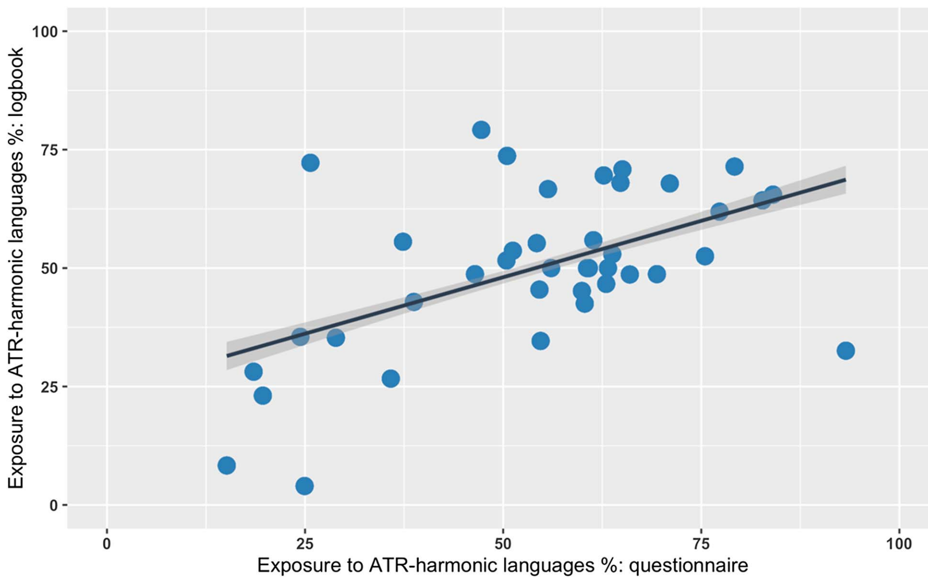
# Results

For descriptive analyses, mean LTs to harmonic and nonharmonic trials were computed per infant. On average, infants' LTs to harmonic trials were longer ($M$ = 8.65 s, $SD$ = 2.40) than to nonharmonic trials ($M$ = 7.81 s, $SD$ = 2.58); see Figure 2. Overall, 28 (70%) of the 40 infants listened longer to harmonic than

**Table 5**
*Average Pitch Values, Pitch Range, Trial Duration (and Their Standard Deviations) Across Trials (After Concatenation)*

| Prosodic features | Harmonic (*SD*) | Non-harmonic (*SD*) |
|---|---|---|
| Average range of pitch values (Hz) | 289.0–318.2 (27.6 − 19.85) | 303.3–320.5 (23.4 − 21.1) |
| Average pitch values (Hz) | 305.58 (24.48) | 310.33 (20.81) |
| Average duration (Sec) | 14.00 (0.00) | 14.00 (0.00) |

**Figure 1**
*Correlation of Language Exposure Measures Retrieved From Questionnaire and Logbook*



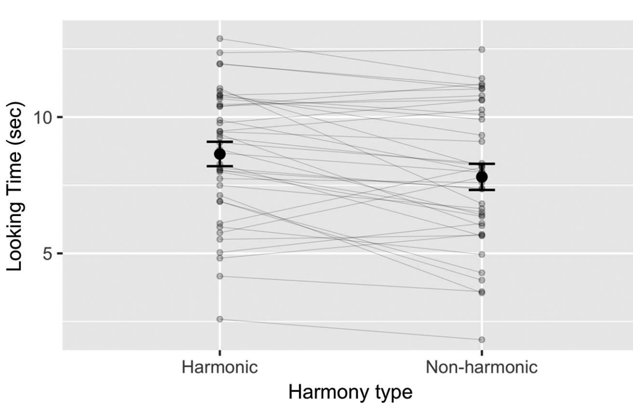

*Note.* ATR = advanced tongue root. See the online article for the color version of this figure.

nonharmonic trials, and 12 infants (30%) listened longer to nonharmonic than harmonic trials.

The linear mixed-effect model (see Table 6) showed a significant effect of harmony ($\beta = -0.347$, $p = .008$, 95% CI [−0.602, −0.092]) with infants looking longer to harmonic than to nonharmonic trials. Moreover, there was a significant effect of trial number ($\beta = -0.379$, $p < .001$, 95% CI [−0.45, −0.30]), indicating that infants' LTs to trials decreased over the course of the experiment (mean LTs and standard deviation for individual trials are given in Supplemental Table S4, and a graph showing the linear decrease of trials is provided in Supplemental Figure S4). There were no significant effects of age ($\beta = -0.067$, $p = .55$, 95% CI [−0.29, 0.15]) and exposure to a language(s) with ATR ($\beta = 0.08$, $p = .798$, 95% CI [−0.52, 0.68]), and no interaction was significant (all $ps > .2$).

Following a reviewer's suggestion, we explored whether the difference in the number of infants with longer versus shorter average LTs to harmonic versus nonharmonic items was significant using a sign test. Results indicate a significant difference ($s = 28$, $p = .02$, median difference = 1.76, 95% CI [0.42, 1.02]), with more infants looking longer to harmonic than nonharmonic items. Last, for the interested reader, we conducted analyses to further explore whether infants' preference for harmonic over nonharmonic trials was predominantly driven by either (+ATR +ATR) or (−ATR −ATR) trials. Results, which can be found in Supplemental Tables S5a and S5b, did not suggest this.

**Figure 2**
*Means and 95% Confidence Intervals for Average Looking Times to Harmonic and Nonharmonic Trials*




*Note.* Dots indicate individual infants' means for the two harmony types.

## Discussion

The aim of the present study was to investigate sensitivity to ATR harmony in 6-month-old multilingual infants learning both ATR and non-VH harmony languages in Ghana (West Africa) and whether their sensitivity is modulated by the relative amount of exposure to (an) ATR harmony language(s). Using the central fixation procedure (Cooper & Aslin, 1990), infants' LTs to ATR harmonic and nonharmonic bisyllabic sequences were recorded. Exposure to ATR harmony language(s) and non-VH languages was assessed using a parental language questionnaire and a diary logbook. In line with our hypothesis, infants displayed longer LTs when hearing harmonic than when hearing nonharmonic bisyllables. The findings suggest that infants are sensitive to ATR harmony. However, we found no evidence for or against the effect of exposure to (an) ATR harmony language on infants' sensitivity to ATR harmony. In what follows, we will discuss these findings, the limitations of our study, and methodological considerations for future field-based experimental infant studies.

**Table 6**
*Final Model Output Showing Parameters of the Linear Mixed Effect Model*

| Fixed effect | Estimate β | *SE* | *t* value | *p* value | 95% CI |
|---|---|---|---|---|---|
| Intercept | 8.23044 | 0.38380 | 21.444 | <.001 | [7.49, 8.97] |
| Harmony | −0.34725 | 0.13060 | −2.659 | .008 | [−0.60, −0.09] |
| Exposure | 0.08038 | 0.31242 | 0.257 | .798 | [−0.52, 0.68] |
| Age | −0.06736 | 0.11279 | −0.597 | .554 | [−0.29, 0.15] |
| Trial number | −0.37879 | 0.03797 | −9.977 | <.001 | [−0.45, −0.30] |
| Harmony × Exposure | 0.07510 | 0.10660 | 0.705 | .481 | [−0.13, 0.28] |
| Harmony × Age | −0.04145 | 0.03830 | −1.082 | .28 | [−0.12, 0.03] |
| Harmony × Trial Number | −0.02753 | 0.03825 | −0.720 | .472 | [−0.10, 0.05] |

*Note*. *SE* = standard error; CI = confidence interval.

This study is the first to find sensitivity to and a preference for VH with ATR and in multilingual infants. Language-specific listening preferences for VH have previously been reported for both backness (Altan et al., 2016; Gonzalez-Gomez et al., 2019; Hohenberger et al., 2016, 2017; Van Kampen et al., 2008) and rounding harmony (Altan et al., 2016; Hohenberger et al., 2016, 2017) in infants learning Turkish and Hungarian but not those learning a non-VH language (French: Gonzalez-Gomez et al., 2019; German: Van Kampen et al., 2008). By extending the previous results on infants' language-specific VH sensitivity to ATR harmony, the literature now contains evidence for infants' early sensitivity to three of the four attested vowel harmony types (Rose & Walker, 2011). Future studies will need to complete this line of research by testing infants' sensitivity to vowel height harmony, the fourth VH system, to assess whether infants acquiring a language with any type of VH show early sensitivity to it.

The fact that here, 6-month-old multilingual infants preferred listening to ATR harmonic syllable sequences over nonharmonic ones is consistent with previous studies that also reported listening preferences for the native VH pattern compared to nonharmonic patterns in 6-month-olds (Altan et al., 2016; Hohenberger et al., 2016, 2017; for meta-analytic evidence, see Sundara et al., 2022). In line with this previous literature, we interpret the effects as a familiarity preference for the native ATR VH pattern occurring in minimally one of the infants' regular language input.

Comparing our findings to previous studies also suggests that VH preferences by multilingual infants, as a group, match those of their monolingual peers at the same age of 6 months (Altan et al., 2016; Hohenberger et al., 2016, 2017; Van Kampen et al., 2008; although note that the Turkish-learning infants in Van Kampen et al., 2008, were raised in Germany and were reported to be exposed to German for 2.4 hr per day on average, for which one may want to label them as bilingual, too). Numerous previous studies have suggested that monolingual and bilingual infants might not differ in the ages at which several early linguistic abilities emerge, such as language and phoneme discrimination (Bosch & Sebastián-Gallés, 2001, 2003; Liu & Kager, 2017; Sundara et al., 2008). The present findings extend this to the level of multilingual infants' phonotactic abilities.

Our analyses did not detect that the quantity of exposure to ATR harmony languages has an effect on infants' sensitivity to VH. If we had observed such an effect, that would have spoken to the role of experience in VH acquisition and multilingual infants' processing of VH patterns. In the absence of evidence for or against such exposure effects, we can speculate about both theoretical and methodological explanations. First, the results could reflect language-specific acquisition of the ATR harmony from the language input. Indeed, prior studies have indicated that infants are sensitive to language-specific phonotactic probabilities (attested vs. unattested consonant clusters: Friederici & Wessels, 1993; high vs. low biphone probability: Gonzalez-Gomez et al., 2014; Henrikson et al., 2020; Jusczyk et al., 1994). In this context, the present results may suggest that multilingual infants are also able to learn language-specific phonotactic probabilities here: The high probability for vowels within words to agree in ATR, from their input, and that even minimal exposure to a language with ATR VH is sufficient for learning this phonotactic regularity.

Second, in light of the possibility that VH may be a reflection of a universal perceptual or learning bias (see Moreton, 2008, for a discussion), the lack of the effect of relative amount of language exposure may also indicate that a presence of such a bias can be maintained on the basis of minimal exposure to (an) ATR VH language(s). This interpretation is in line with previous studies that have suggested effects of perceptual or learning biases in relation to VH. For example, English-learning infants used VH cues to segment bisyllabes from an artificial language speech stream after minimal exposure to VH patterns—an effect that cannot be explained by their experience, as English does not show VH (Mintz et al., 2018). Moreover, VH learning biases are attested for adult speakers who more readily learn VH patterns than unnatural patterns (Martin & Peperkamp, 2020) and first language speakers of harmony language who use this bias in learning a new artificial language (LaCross, 2015). A further reason why our results may reflect a perceptual bias is because the current results resemble those for another pattern that could be grounded in perceptual biases, namely the trochaic bias: German/French simultaneous bilingual infants who receive as little as 30% exposure to German (a trochaic language) show a bias for trochaic patterns that is not detected to be modulated by the amount of exposure to German (Bijeljac-Babic et al., 2016). Similarly, German/French simultaneous bilingual adults showed, irrespective of their bilingual experience, rhythmic grouping biases that are otherwise modulated by language-specific experience (Boll-Avetisyan et al., 2020). Considering the results from these prior studies, little input may be enough for 6-month-old multilingual infants to learn VH or maintain a perceptual bias for VH. Whether VH preferences are purely learned from the input or based on universal biases is a complex theoretical debate that cannot be easily resolved. Potentially, future research will shed more light on this.

A third (possibly complementary) explanation of the apparent absence of an exposure effect is that multilingual infants might have distinct phonotactic systems for each of their native languages and are able to switch between them. Similar to bilingual infants (Antovich & Graf Estes, 2018; Orena & Polka, 2019), multilinguals may activate a specific language processing mode based on the linguistic context at any given time (see Grosjean, 2001). Infants in our experiment may thus have employed an Akan processing routine, leading them to perceive the stimuli without ATR VH as ill-formed—even though such items or words might be permissible in one of their other languages. The speech context of the experiment may have put infants in an Akan processing mode since the experimenter and the infant's caregiver predominantly spoke Akan before the experiment (about 90% of the time per child), and the stimuli were pronounced as Akan, which may have contained some Akan-sounding phonological and subphonemic features. To our knowledge, the ATR contrast was the only Akan-specific feature in these stimuli, and we are unaware whether this could have activated an Akan-only processing mode. Future studies using different language context conditions and stimuli should address under which conditions multilinguals apply knowledge of a specific VH system.

A final, more methodological explanation of the null result for the amount of exposure to (an) ATR harmony language(s) modulating listening preferences could be that our estimates of language exposure, obtained via caregiver reports, may have been inaccurate or unreliable, even though estimates from the questionnaire and logbook were correlated. Infants growing up in Ghana are exposed to a wide range of languages (in our sample, between two and five different languages per child) in both child-directed and overheard speech from different contexts (at home, social/religious gatherings, and media) and with many different caregivers (in our sample, between two and six). Therefore, the caregivers who completed the questionnaire and logbook diary might not have been accurate in reporting language input from all caregivers, leaving us unable to find associations with the infant's perception. For future research, using daylong recordings (Casillas et al., 2020) or asking at least two or three primary caregivers per child to provide language exposure estimates for each child would be a good way to avert this issue.

While there have been some studies with children aged 3 years and above in Ghana (e.g., Amoako & Stemberger, 2022a, 2022b; Omane & Höhle, 2021), the present study represents the first psycholinguistics research on infants growing up in Ghana. Our experiences support and illustrate several issues raised in the ongoing discussion on diversifying language acquisition research (e.g., Aravena-Bravo et al., 2023; Cristia et al., 2023; Kidd & Garcia, 2022; Paradis, 2022; Singh et al., 2023). First, given the prevalent multilingualism and its immense diversity in Ghana's cities, it would have been impossible to recruit a monolingual control group or a homogenous multilingual group. For example, in our sample, not all infants were exposed to the same languages or even the same number of languages. As a result thereof, our multilingual group could also not consist of infants with a specific ratio of exposure, such as a minimum of 20% of exposure to their least frequent language, as commonly done in studies with bilingual infants (see Bosch & Sebastián-Gallés, 1997, 2001; Byers-Heinlein, 2015; Sebastián-Gallés & Bosch, 2009). A further methodological challenge was to obtain all demographic information that would be standard for infant development studies in the Western context. For example, in Ghana, as in many other African countries (see Allotey & Reidpath, 2001; Bayat, 2015), it is considered culturally inappropriate to ask questions about developmental disorders and disabilities because of societal stigmatization based on religious beliefs that these conditions are a punishment from the gods or a curse on their family (see Grischow et al., 2019, for a review). While the first author, a native of Ghana, was able to obtain information about these conditions by using culturally appropriate indirect ways of inquiring, the cultural context makes it impossible to be sure that all parents responded honestly. Hence, to facilitate communication with parents, we recommend for future studies in Africa to consider dropping those questions. Last, while in the North American context, it is recommended to obtain information about infants' race, it would have been culturally inappropriate to ask race-related questions in Ghana; hence, we did not gather this information. We recommend that other researchers conducting field-based language development studies adopt culturally appropriate practices in line with the studied communities' culture, beliefs, and customs (see also Singh et al., 2024). Notably, this will require that journal editors and reviewers, who are key stakeholders in achieving diversity in our field, will recognize the need for new "standards" (see Paradis, 2022, for a discussion). In sum, if we aim for diversity and, more specifically, studies to reflect the diverse conditions of multilingualism, some standard procedures and protocols need to be adapted.

We finally turn to some implications of the present study on preregistering field-based research. We preregistered our study plan (see https://doi.org/10.17605/OSF.IO/9M3Z4) and met the target number of 40 participants. Reaching this sample size required setting up additional test sites and being more involved with individual participants than originally planned (e.g., we had to pick up some parents by car from their homes to get them to the test location, and most families preferred us to collect the logbooks and baby vests from their homes). While our additional effort paid off, we must note that field researchers often do not have control over meeting targets because field stays are limited in time, and there are uncertainties about participant availability. Future field-based studies may thus want to preregister a time at which testing will end, even if the target number has not been reached (see Open Science Framework guide, Center for Open Science Preregistration). This way, we can promote transparency and replicability in language acquisition, not only in mainstream lab-based studies but also in field research.

In conclusion, the current article investigated multilingual infants' sensitivity to ATR harmony. Our results show that by the age of 6 months, multilingual infants are sensitive to the VH patterns in one of their languages, even though they are learning other languages without VH. Comparisons to previous work suggests that the processing of VH may be similar between monolingual and multilingual infants. Our findings do not provide evidence of the relative amount of exposure to (an) ATR harmony language(s) modulating VH processing in infants, raising questions about innate mechanisms and language-specific factors influencing VH processing, especially in multilingual infants. Future research on understudied languages and multilingual populations in Africa is encouraged to shed more light on their early language processing abilities and how early experience with diverse languages may interact with their language development.

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