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Perception of a native vowel contrast by Dutch monolingual and bilingual infants: A bilingual perceptual lead

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Abstract

Purpose: Facing previous mixed findings between monolingual and bilingual infants' phonetic development during perceptual reorganization, the current study aims at examining the perceptual development of a native vowel contrast (/I/-/i/) by Dutch monolingual and bilingual infants.
Design: We tested 390 Dutch monolingual and bilingual infants from 5 to 15 months of age through a visual habituation paradigm.
Data and analysis: Mixed-effect model analyses were conducted within 320 infants, with infants' $\log_{10}$ transformed looking time as the dependent variable, age (4-level) and language background (2-level) as the fixed factors, and participant and order (2-level) as the random factors.
Conclusions: All infants show weak initial sensitivity to the contrast regardless of language background(s), and sensitivity improves with age. By the second half of the first year, infants discriminate the contrast, indicating the emergence of the relevant vowel categories. In addition, a *perceptual lead* is observed in bilingual infants, probably due to: 1) a perceptual transfer from the close-category counterpart of the other native language; 2) heightened acoustic sensitivity in bilingual infants given their rich linguistic experience; and 3) a general bilingual cognitive advantage. The influences of contrast salience and bilingualism on language development are discussed.
Originality: Overall, these findings constitute an extension of existing work on vowel perception and display a novel *acceleration effect* for the bilingual infants in phonetic perception. In addition, we propose a novel *heightened acoustic sensitivity hypothesis*, arguing that bilingual infants may pay more attention to acoustic details in the input than their monolingual peers.
Significance: The observed progressive phonetic discrimination pattern of the native contrast contributes to our knowledge in infant language development, and specifically perceptual reorganization patterns, in the first year after birth. The observed acceleration effect, along with its explanations, provides new insights into the influence of bilingualism and potential bilingual advantages in infancy.

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Introduction

In recent decades, much attention has been paid to infant language development, and much research has focused on perceptual tuning to native sound inventories during infancy. Infants are born with the ability to discriminate a wide range of native and non-native contrasts regardless of their language background (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). In the vowel domain, 1- to 6-month-old English infants distinguish the native /a/-/i/, /a/-/u/, and non-native [pa]-[pã], /a/-/ɔ/ contrasts (Kuhl, 1979, 1983; Trehub, 1973, 1976;). English or Spanish newborns of 0 to 1 day display initial sensitivity in vowel space closely matching native vowel targets, and adult-like perception of /i/, /u/, /y/ and /ɯ/ (Aldridge, Stillman, & Bower, 2001). English infants of 2 months discriminate the native /I/-/i/ contrast in a non-categorical manner (Swoboda, Kass, Morese, & Leavitt, 1978; Swoboda, Morse, & Leavitt, 1976).

During their first year of life, infants tune in to the native speech categories (Werker & Tees, 1984). This perceptual tuning process manifests itself as the maintenance and realignment of their initial sensitivity to native contrasts (Burns, Yoshida, Hill, & Werker, 2007), facilitation in discriminating native contrasts (Polka Colantonio & Sundara, 2001; Kuhl et al., 2006; Sundara, Polka, & Genesee, 2006, Tsao, Liu, & Kuhl, 2006), and a decrease in sensitivity to non-native contrasts (Anderson, Morgan, & White, 2003). In the vowel domain, previous studies have shown that the language-specific tuning time window for vowels occurs around the second half of the first year after birth. American and Swedish infants of 6 months show a strong "magnet" effect when discriminating two sets of vowel stimuli, the prototype of which represented either English /i/ or Swedish /y/, their perception being prone to the prototype of the phonetic categories of the native language (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). This effect is also found in English infants of 4–6 months whose perception represent language-specific experience when discriminating the German /ʊ/-/ʏ/ and /u/-/y/ contrasts (Polka & Werker, 1994, but see Polka & Bohn, 1996 for a successful non-native contrast discrimination). Spanish and Catalan infants of 4 months are sensitive to the Catalan /e/-/ɛ/ contrast, whereas at 8 months, only Catalan infants show successful discrimination (Bosch & Sebastián-Gallés, 2003a). The mismatch negativity amplitude in 12-month-old infants is higher for native vowel phonemes and lower for non-native ones compared with 6-month-olds (Cheour, Ceponiene, Lehtokoski, Luuk, Allik, Alho, & Näätänen, 1998).

Controversy occurs in bilingual studies, showing different results regarding monolingual and bilingual infants' development of native vowels. The debate focuses on whether bilingual infants follow the same perceptual tuning trajectory as monolingual infants in the first year of life. Studies on 8-month-old Spanish-Catalan bilingual infants have revealed a temporary loss of discrimination of Catalan-specific /e/-/ɛ/ and Catalan/Spanish /o/-/u/ contrasts, though they recover sensitivity at 12 months (Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009). A follow-up study demonstrates that 8-month-old Spanish-Catalan bilingual infants discriminate the /e/-/ɛ/ contrast in an adapted anticipatory eye-movement paradigm (Albareda-Castellot, Pons, & Sebastián-Gallés, 2011), and similar success has been found in English-Spanish bilingual infants of 8 months when discriminating the English /e/-/ɛ/ contrast (Sundara & Scutellaro, 2011). It remains unclear whether the /o/-/u/ contrast will show similar results under a different paradigm. In addition, bilingual Spanish-Catalan children of 3–8 years discriminate the /e/-/ɛ/ contrast if they are Catalan-dominant, but not if they are Spanish-dominant (Ramon-Casas, Swingley, Sebastián-Gallés, &

Table 1. The average F1 and F2 mean (standard deviation, SD) values of the vowels (in Hz).

	F1	F2
/I/	409 (10)	2280 (106)
/i/	370 (25)	2597 (106)

Bosch, 2009), revealing potential input-related vulnerability in bilingual perception. Note that similar mixed findings have also been reported in native consonant contrast discrimination between monolingual and bilingual infants during the perceptual tuning stage (Bosch & Sebastián-Gallés, 2003b; Burns et al 2007; Sundara, Polka, & Molnar, 2008). Several accounts have been proposed for the reported delay, including, but not limited to, the acoustic properties and salience of the contrast, frequency and distributional properties in the input, rhythmic similarity or segmental variation (cognate words) between languages, phonetic space (the density of phonetic categories), processing differences between vowels and consonants, task effects (tokens in use, number of talkers, paradigm, etc.), and social-indexical factors (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011; Sundara & Scutellaro, 2011).

To improve our understanding of vowel perception abilities in monolingual and bilingual infants, we investigate the developmental trajectory of Dutch monolingual and bilingual infants' perception of a native vowel contrast across ages. In addition, the current study takes a broader view and makes a novel contribution by testing perception of a native vowel contrast by infants from a heterogeneous language background, allowing for a greater chance of targeting the general effect of bilingualism. In light of previous studies, we expect either a similar developmental pattern between monolingual and bilingual infants or a temporary delay in the time-course of language-specific perceptual tuning for bilingual infants.

General method

Stimuli

To choose a language-specific contrast, we tested infants on the two Dutch vowels, /I/ and /i/ (e.g. *rit* 'ride' vs. *riet* 'reed'), which differ in spectrum (first (F1) and second (F2) formant) but not duration (Adank, Smits, & Van Hout, 2004; Rietveld, Kerkhoff, & Gussenhoven, 2004; Curtin, Fennell, & Escudero, 2009). The syllables /bIp/ and /bip/ spoken by a female Dutch speaker were recorded in a sound-isolated booth at the Utrecht University phonetic lab with a DAT Tascam DA-40 recorder and a Sennheiser ME-64 microphone. Five tokens were selected for each sound category to create within-speaker variation. Stimuli syllable duration was controlled via PRAAT across tokens (Boersma & Weenink, 2012). The lengthened vowel duration (277ms on average) aimed at making the stimuli more friendly and attractive to the infants. The VOT values of syllable onsets and offsets /b/ and /p/ were set around 72ms and 1ms, respectively. The other natural properties of the contrast were maintained. The average duration, F1 and F2 values of the contrast are shown in Table 1. Prior to the infant experiment, we pre-tested the contrast on 30 Dutch adults via AX and AXB discrimination paradigms, who discriminated this native contrast with ceiling performance.

Participants

A total number of 233 monolingual and 157 bilingual Dutch infants aged 5–6, 8–9, 11–12 and 14–15 months participated in the study. All parents reported normal hearing for their children. All bilingual infants listened to Dutch as one of their native languages, and the other language varied across participants. No purely spectral /I/-/i/ contrast occurs in the other languages, although a similar /I/-/i:/ contrast occurs in other Germanic languages, such as English and German, where it is marked not only spectrally, but also by duration. The degree of exposure (DoE) to the non-dominant language was no less than 20% via a Multilingual Infant Questionnaire designed by the authors. The mean (SD) DoE to Dutch is 53.97% (17.65). Eventually, data from 320 participants were included for analysis, with 50 monolingual and 30 bilingual participants per age group. Among bilingual infants, 56.67% were dominant (more than 50% of exposure) in Dutch. Data from70 participants were excluded from analysis, the reasons being: fussiness or crying (21), unable to habituate (max 12 trials in the habituation phase) during the experiment (4), inattentive during the experiment (6), equipment error (1); looking time (LT) less than 2 seconds for both trials in the test phase (15), and individual average LT for each sound category in the test phase more than 2 SD from the mean of the age group (23).

Procedure

The performance of infants' discrimination was assessed via a visual habituation paradigm (Colombo, 1993). The auditory stimuli were presented along with a visual pattern (static bull's eye). Infants' LT to the screen was measured at each trial, of which the auditory presentation was contingent on infants' looking. A trial ended if an infant looked away for more than 2 seconds or reached a maximum duration of 45 seconds. The paradigm consisted of three phases: habituation, test, and post-test. In the habituation phase, infants heard repeated tokens of one sound category. The habituation criterion was reached when the mean LT of the last three trials in the habituation phase fell below 65% of the mean LT of the first three trials, indicating a significant decrement in LT. Then infants received two trials in the test phase in which tokens that were different categories from the habituation tokens were presented. Discrimination was indicated by a significant LT recovery upon hearing the new stimuli to the same visual target. Given previous literature on infant vowel perception, we expected a higher LT in the test phase than in the end of the habituation phase. The post-test phase included a novel stimulus verifying infants' general attention and ended with a happy Dutch song to ensure a good mood for infants before leaving the test cabin.

During the experiment, infants sat on their caretaker's lap in the test booth, facing the screen and the camera. No visual or auditory interference was present in the booth. An experimenter observed the trials through a closed circuit TV in a room adjacent to the test booth, using a button box to record infants' LT. The paradigm was designed via the ZEP program (Veenker, 2007). The inter-stimulus interval was set at 1 second in all phases. Within each age group, infants were either habituated on /bip/ and tested on /bIp/, or vice versa (the order factor). Both experimenters and parents were blind to the stimuli.

Results

A mixed-effects model analysis was conducted in SPSS with infants' difference of $\log_{10}$ transformed LT[1]as the dependent variable, age (4-level) and language background (2-level) as the fixed factors, and participant and order (2-level) as the random factors. The factor of age was significant $F(3, 325) = 8.082$, $p < .001$ (one-tailed)[2]. In addition, pairwise comparisons showed a significant difference between monolingual and bilingual infants at 8–9 months (df = 325, Confidence Interval (CI) [–.220, .002], $p = .026$, one-tailed) but not at the other age groups (n.s.). Looking into each age, the mixed model reported the same significant difference in the 8–9-month-old group ($t = -1.971$, CI [–.219, .001], $p = .026$, one-tailed) but not at the other age groups (n.s.). Paired

Table 2. Paired sample *t*-test of infants' $\log_{10}$ transformed LT in the phase change (one-tailed).

	Monolingual			Bilingual		
	t (df)	*p*	CI	*t (df)*	*p*	CI
5–6m	0.650 (1, 49)	= .260	[–.050, .098]	0.340 (1, 29)	= .368	[–.076, .106]
8–9m	–0.742 (1, 49)	= .231	[–.092, .042]	–2.871 (1, 29)	= .004	[–.229, –.039]
11–12m	–6.029 (1, 49)	< .001	[–.201, –.100]	–3.232 (1, 29)	= .002	[–.238, –.054]
14–15m	–3.372 (1, 49)	< .001	[–.207, –.052]	–3.219 (1, 29)	= .002	[–.278, –.062]

sample *t*-tests were conducted for each age and language condition with $\log_{10}$ transformed LT in the phase change as the variables (1-tailed, Table 2). Results showed that neither 5–6 nor 8–9 month-old monolinguals discriminated the contrast. Robust discrimination occurred at 11–12 and 14–15 months. As for bilingual infants, all age groups except 5–6 months discriminated the contrast. In sum, the current results reveal a progressive development in discrimination for both groups. The LT surged at 11–12 months for monolinguals and at 8–9 months for bilinguals (Figure 1).

An analysis was conducted for bilingual infants at 8–9 months regarding language dominance (Dutch vs. non-Dutch dominant). No significant difference was observed regarding this potentially influential factor. In addition, the order of vowels presented in the habituation and test phases was not a significant factor, hence no asymmetric vowel discrimination was found in our current experiment. Table 3 depicts some details of the participants' language background.

Discussion

The data from the discrimination experiment show improvement of Dutch infants' perception of the /I/-/i/ contrast during the first 15 months of life, in which two main stages can be observed: the initial lack of sensitivity, followed by successful discrimination in the second half of the first year of life. Given the results of previous studies, three unexpected issues need to be addressed: 1) a lack of initial sensitivity to a native vowel contrast for all infants at 5–6 months; 2) an extended language-specific vowel perceptual tuning time window in monolingual infants compared with previous studies; 3) an approximate 3-month ***perceptual lead*** for bilingual infants compared with their monolingual peers.

First, no initial sensitivity was observed in the perception of the native /I/-/i/vowel contrast for Dutch monolingual and bilingual infants. This is unlikely to have been caused by a task effect, since infants' attention, reflected by LT, remains high in the test phase. One explanation would be that, just like some consonant contrasts (Narayan, Werker, & Beddor, 2010; Sato, Kato, & Mazuka, 2012), the Dutch contrast tested in the current study may be relatively acoustically difficult to distinguish at the initial stage. Dutch infants may initially perceive the contrast as one category, and gradually divide that category into two narrower ones with accumulated language exposure from the ambient environment. In addition, previous studies have shown that the language-specific perceptual tuning process is elastic (Werker & Tees, 2005). Some native contrasts cannot be discriminated until a relatively later stage. Tagalog infants of 10–12 but not 6–8 months discriminate the native /na/-/ŋa/ contrast, although they have no problem discriminating the native /ma/-/na/ contrast at both ages (Narayan et al., 2010). English infants do not perform well when discriminating the native stop-fricative /d/-/ð/ contrast in the first year after birth (Polka et al., 2001). Japanese infants do not acquire the single vs. geminate obstruent /pata/-/patta/ and the vowel duration / mana/-/ma:na/differentiation until 9.5 months (Sato, Sogabe, & Mazuka, 2010; Sato et al., 2012).

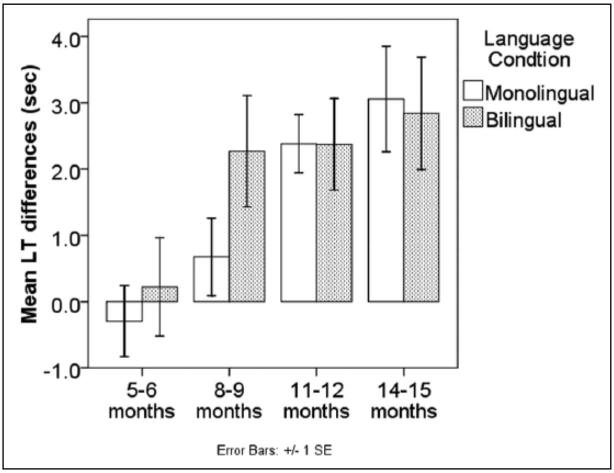

Figure 1. Infants' mean LT differences in the phase change
(Error bar: 1 standard error (SE))

These findings indicate that the acoustic salience of contrasts plays an important role in speech perception and phonological development in infancy. A potential counter argument shows that 2-month-old English infants discriminate a similar English /I/-/i/ contrast (Swoboda et al., 1976). The formant values used are similar between Swoboda et al. and the current study, yet the testing methods differ. In the previous study, the high-amplitude sucking procedure is adopted with a higher dropout rate (82% as opposed to 18%) and longer average habituation time (5 minutes as opposed to 1.5 minutes).

Second, with accumulated native experience, infants' sensitivity shifts towards the native sound inventory, and stabilizes by the second half of the first year of life. Their perceptual pattern is argued to be adult-like. However, our findings show that Dutch monolingual infants do not discriminate the contrast until 11–12 months, later than the usual hallmark of language-specific tuning for vowel contrasts (6–8 months, Kuhl et al., 1992; Polka & Werker, 1994; Sebastián-Gallés, 2006). The language-specific tuning process is thus likely to be contrast dependent, influenced by acoustic salience (Liu & Kager, 2014) and perhaps factors such as input frequency. These potential factors need to be studied in future research.

Third, unexpectedly, bilingual infants showed robust discrimination to the native vowel contrast at 8–9 months, 3 months prior to monolingual infants. We attribute this novel finding of ***perceptual lead*** to several explanations: 1) a perceptual transfer from the close-category counterpart of the other native language; 2) heightened acoustic sensitivity in bilingual infants given their rich linguistic experience; and 3) a general bilingual cognitive advantage.

First, if we consider the current discrimination data as an indication of the development of native categories, bilingual infants are ahead of their monolingual peers despite having less Dutch exposure (mean DoE: 54%). However, our bilingual participants come from various language backgrounds, and some infants may hear a contrast from the other language that is similar to the Dutch contrast here tested (e.g. /I/-/i:/ or /i/-/e/ for Dutch-English/German bilinguals, see Bohn & Polka (2001) for some similar German contrasts discrimination by native monolingual infants) supported by the durational cue apart from spectrum. In that case, perceptual assimilation and facilitation may occur. Assimilation-wise, these infants may categorize close categories in perceptual space from two languages into one. Such assimilation may occur in the early phase, and the

Table 3. The other first language background of Dutch bilingual participants with detailed number of each language at 8–9 months, the key stage when the difference was found between monolingual and bilingual infants.

Language	Total No. Participants	At 8–9m No. Participants	At 8–9m robust discrimination
Bahasa	1	0	0
Czech	2	1	1
English	36	9	5
French (European)	13	3	1
German	34	6	4
Hebrew	1	0	0
Italian	3	0	0
Japanese	2	0	0
Mandarin Chinese	5	1	1
Norwegian	1	0	0
Portuguese	3	1	0
Russian	3	1	1
Spanish	26	5	2
Swedish	1	0	0
Turkish	24	2	0
Wu (southern)	2	1	1
Total	**157**	**30**	**16**

degree of separation may be input-dependent in the later phase, similar to how Spanish-Catalan bilingual infants with different language dominance show different perception of the Catalan-specific /e/-/ɛ/ contrast (Ramon-Casas et al., 2009). Facilitation-wise, these infants may use specific cues (e.g. the spectrum cue) in close contrasts of the other language to facilitate Dutch /I/-/i/ perception. It is difficult to measure the speech quality and quantity of close categories given parents' diverse language backgrounds and speaking patterns, as well as the number of infants tested in the experiment (Table 3). We leave this hypothesis open to discussion.

Regarding the second hypothesis, if the perceptual lead is introduced by a general influence of bilingualism, we propose a ***heightened acoustic sensitivity hypothesis***: bilingual infants pay more attention to acoustic details in the input than their monolingual peers. This hypothesis may originate from, or be intertwined with:1) the complex language environment bilingual infants face; 2) one tightened phonetic space from two languages, forcing bilingual infants to be sharp in detecting native sound patterns; 3) better neural plasticity and less neural commitment, avoiding the formation of false categories; etc. In addition, this hypothesis may be one of the explanations for previous findings showing bilingual infants' enhanced sensitivity to non-native contrasts compared with monolingual infants (Byers-Heinlein & Fennell, 2014, Liu & Kager, 2013). Nevertheless, for initially discriminable contrasts that require realignment or strengthening, too much attention to acoustic detail may not help in category formation / boundary stabilization, resulting in mixed findings (temporary delay or confusion) in previous literature (consonant: Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés, Bosch, & Pons, 2008; Garcia-Sierra et al., 2011; Liu & Kager, 2015; vowel: Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009; tone: Singh & Foong, 2012), and a later category formation than monolinguals (Kuhl et al., 2008; Petitto, Kovelman, Dubins, Jasinska, & Shalinsky, 2012). In brief, apart from input and phonetic space, heightened acoustic sensitivity may be another factor that plays a role in bilingual speech development. Facing less input from each language compared with monolinguals, bilingual infants may use different learning strategies, pay attention to alternative cues from the input and keep pace with monolinguals along the linguistic milestones (Mattock, Polka, Rvachew, & Krehm, 2010; Werker, 2012).

Third, bilingual infants have been shown to present some cognitive advantages over their monolingual peers. Bilingual infants of 7 months show better inhibition ability (Kovács & Mehler, 2009a, 2009b). In addition, 6-month-old bilingual infants illustrate greater efficiency in stimulus encoding and recognition memory in visual habituation tasks (Singh, Fu, Rahman, Hameed, Sanmugam, Agarwal, ... Rifkin-Graboi, 2014). Bilingual infants' perceptual lead at 8 months may be attributed to their general cognitive advantage surfaced in visual habituation tasks. The hypotheses raised by the current findings should be examined in future studies.

To conclude, we report Dutch infants' progressive perceptual developmental pattern of a native vowel contrast, from lack of sensitivity at the initial stage to successful discrimination. We also report some differences between infants from a monolingual and a bilingual environment in the second half of the first year of life. We hypothesize that these differences may be caused by general linguistic and/or cognitive advantages stemming from bilingualism. On a final note, since we only tested infants' discrimination, we should be cautious in interpreting the current results as forming native categories. Nevertheless, Dutch infants' discrimination patterns across age and language backgrounds provide valuable insights into the influence of language exposure on their phonemic development.

Research highlights

1) Lack of initial sensitivity to a native vowel contrast for Dutch infants at 5-6 months
2) An extended language-specific perceptual tuning time window for the vowel contrast in Dutch monolingual infants compared to previous studies
3) A perceptual lead observed in Dutch bilingual infants when perceiving a native vowel contrast

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Notes

1. The log transformation ensures the normal distribution of the dataset to fit the model.
2. As no re-presentation of habituation stimuli appeared in test trials, the results could be due to regression to the mean following attainment of the habituation criterion. However, this interpretation is unlikely given the performances across age and language groups.

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