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Language experienced *in utero* affects vowel perception after birth: a two-country study

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Abstract

Aims—To test the hypothesis that exposure to ambient language in the womb alters phonetic perception shortly after birth. This two-country study aimed to see if neonates demonstrated prenatal learning by how they responded to vowels in a category from their native language and another nonnative language, regardless of how much postnatal experience the infants had.

Method—A counterbalanced experiment was conducted in Sweden (n=40) and the USA (n=40) using Swedish and English vowel sounds. The neonates (mean postnatal age = 33 hrs) controlled audio presentation of either native or nonnative vowels by sucking on a pacifier, with the number of times they sucked their pacifier being used to demonstrate what vowel sounds attracted their attention. The vowels were either the English /i/ or Swedish /y/ in the form of a prototype plus 16 variants of the prototype.

Results—The infants in the native and nonnative groups responded differently. As predicted, the infants responded to the unfamiliar nonnative language with higher mean sucks. They also sucked more to the nonnative prototype. Time since birth (range: 7–75 hours) did not affect the outcome.

Conclusion—The ambient language to which foetuses are exposed in the womb starts to affect their perception of their native language at a phonetic level. This can be measured shortly after birth by differences in responding to familiar vs. unfamiliar vowels.

Keywords

fetal; language; learning; neonatal; vowels

Introduction

It is now well established that listening to a specific language early in life alters young infants' perception of speech sounds even before they begin to produce their first words. Within the first months of postnatal life, infants discern differences between phonemes^{1–4} and they group consonants into perceptual categories regardless of whether the sounds are from their native or a nonnative language^{5,6}. Between six and 12 months, their ability to discriminate between different native language speech sounds increases, but it declines sharply for nonnative sounds^{7,8}.

A question often raised, both for theoretical and practical reasons, is: how early in life does experience with language affect infants? A laboratory study showed that the effect of

experience appears earlier for vowels than for consonants and can be measured by six months of age. Testing in Stockholm and Seattle revealed that infants in both Sweden and the USA were able to group native vowel sounds into categories, but were unable to do so for nonnative vowels⁹. It is not surprising that experience with vowels would affect perception earlier than consonants, because vowels are louder, longer in duration and carry salient prosodic information (melody, rhythm and stress).

This paper reports the results of an investigation into an area that has not been studied before: does experience in the womb affect infants' perception of vowel sounds? We already know that hearing begins at the onset of the third trimester of pregnancy and that sound is transmitted primarily through bone conduction, from the amniotic fluid through the foetal skull and into the inner ear¹⁰. Reliable foetal responses to pure tones presented via a loudspeaker have been recorded as early as 12–13 weeks before birth¹¹ and late-term fetuses not only detect vowels^{12,13} but show heart rate changes when the vowels /a/ as in *pot* and /i/ as in *fee* shift position in [ba]-[bi] to [bi]-[ba]¹⁴. Recordings made *in utero* show sufficient preservation of formant frequencies to make vowel discrimination possible and intelligibility tests show that adults can identify about 30–40% of phonetic content of speech recorded in the womb^{15,16}. What is unknown, however, is whether an ability to *detect* and to *discriminate* vowel sounds in the womb is accompanied by an ability to *learn* vowels from prenatal experience¹⁷.

Learning from natural exposure to sound has been shown in neonatal experiments using entire sentences or phrases, and this is thought to reflect learning about *prosodic* aspects of language^{2,18–22}. However, newborns have been considered to be *phonetically* naïve— influenced only by their innate, universal capacities—and ready for learning through postnatal experience. The aim of the current study was to investigate whether neonates are capable of learning phonetically *in utero* by examining the effects of language experience on phonetic perception at the youngest feasible age.

Study participants were from Stockholm and Tacoma, Washington, and the stimuli for the neonate study were the same as those used in the Sweden/USA study of six-month-olds by Kuhl *et al.*, 1992⁹. The native and nonnative vowels were the English vowel /i/ as in *fee* and the Swedish vowel /y/ as in *fy* (like the German /ü/). The 1992⁹ experiment used a prototype of each of the two native vowels and 32 variants of each category to test vowel category perception. Speech prototypes are defined as the best example of a category as judged by adult speakers of the language²³. In the present study, our goal was to ascertain whether neonates in the two countries showed any tendency to group native vowels into a category, pre-dating the abilities of six-month-olds. If neonates showed an effect of learning, and if time since birth did not affect how they responded, it would provide evidence of learning *in utero*. We used a contingent procedure in which each sucking response by the infant would produce a particular vowel sound and the number of sucking responses provided a measure of the infant's interest in each sound. We hypothesised that infants would show less interest in the familiar sound stream (native language vowels) due to the vowels' equivalency with each other as members of a category and their repetitive nature. In contrast, the nonnative vowels would seem to be in a constantly changing sound stream and therefore more likely to attract the infant's attention^{24,25}. We used the prototype vowel of the English and Swedish vowel category as well as variants of the prototype of each of these two categories used by Kuhl *et al.* (1992)⁹.

We specifically predicted that infants in the native language group would show a lower level of attention to the familiar category of native vowels and, as a result, suck their pacifiers less often when they heard these than infants in the nonnative group. We also predicted that

the distinction could be particularly evident for the prototype vowels, given that prototypes are considered representative of categories as a whole²⁶.

Method

Participants

Neonates ($M = 32.8$ hrs postnatal age, range = 7–75 hrs) were tested in hospitals in Tacoma, Washington, USA ($N = 40$) and Stockholm, Sweden ($N = 40$). Infants were eligible if: a) pregnancy, birth and neonatal hearing tests were typical, b) the maternal native language was English (in Tacoma) or Swedish (in Stockholm) and c) the infant's mother did not speak a second language more than rarely during the final trimester of pregnancy, as assessed informally in the USA and by a questionnaire in Sweden. In addition to the 80 total infants in the study, 15 additional infants were excluded from the analysis for: cessation of sucking during the experiment (5), fussiness (1), drowsiness (5), parental interference (1) and equipment or experimenter error (3). This represents a low (16 %) attrition rate for neonatal behavioural tests of perception. Half of the infants in each country were assigned to hear the Swedish vowel stimuli and half the English. There were no statistically significant differences between the two groups in terms of gender, test age, gestational age, birth weight or number of sucks in five minutes.

Stimuli

The stimuli from Kuhl et al. (1992)⁹ were computer-generated sound files of 17 different examples of the English front unrounded vowel /i/ as in “fee” and 17 instances of the Swedish front rounded vowel /y/ as in “fy.” The vowel inventories in both Washington State and Sweden do not include the nonnative vowels used in the study. The prototype vowel for each language had been experimentally determined by native speakers in Seattle and Stockholm, who rated the vowels as the best representatives of the category^{9,27}. The 16 vowel variants were created by altering the first and second formant frequencies of the prototype in a step-wise fashion, to create two concentric rings of eight stimuli around each prototype (see Figure 1). The vowel stimuli were each 500 ms in duration and were delivered at 72 dB (Bruel & Kjaer Model 2235, Scale A) through headphones (Grado 225).

Design, equipment and procedure

A between-subjects design was chosen because exposure to one vowel category could affect performance on the second vowel category. This also reduced the session time and attrition rate. Sessions were conducted in a quiet room with infants lying supine in their bassinets with headphones placed next to their ears (see Figure 2). Each infant was offered a pacifier and the data collection began if the infant accepted it and started sucking in a typical, rhythmic burst/pause pattern. The protocol stipulated a five-minute test period to allow presentation of each of the 17 vowels in the set.

Pacifiers were fitted with a sensor connected to a computer that delivered auditory stimuli when the infants sucked on the pacifier. When they completed the second suck in a burst, one of the 17 stimuli was presented in random order. Each vowel was repeated until there was a pause in sucking of one second or longer. Resumption of sucking resulted in a new vowel stimulus from the set. Equipment consisted of an air pressure sensor for the pacifier, A/D converter, sound amplifier (Klevang Electronics, Portland, Oregon) and a Dell laptop computer with custom software (Klevang Electronics). An air pressure threshold was set so that virtually all the sucks after the first one in a sucking burst resulted in sound presentation. Stimuli were delivered in random order without replacement. The equipment used in both countries was identical and the same experimenter (CM) conducted the tests in both countries using the same protocol. Examination of the randomisation showed that the

prototype appeared in all 17 possible serial positions, was roughly equally distributed among positions ($\chi^2 = 15.6, p = .48$) and the test groups did not differ when it came to the serial position of prototype (Kruskal Wallance $\chi^2 = 1.61, p = .66$). Average time to complete the series of 17 stimuli was 135.1 seconds ($SD 50.2$).

Results

Data from the first presentation of each of the 17 stimuli were analysed and the dependent measure was number of sucks per vowel stimulus. A mixed ANOVA was conducted to examine the effects of Language Experience: (native vs. nonnative), Prototypicality (prototype vs. nonprototype) and Country (USA vs. Sweden), with hours since birth as a covariate. We examined hours since birth to determine whether learning effects could be attributed to pre- vs. postnatal experience. There was no significant main effect ($F_{1,75} = .04, p = .85$) of hours since birth, nor any interaction effects with hours since birth. As a result, this factor was not included in subsequent analyses.

The effect of Language Experience was significant ($F_{1,75} = 4.95, p = .029$), with a greater number of sucks overall during the nonnative ($M_{Nonnative} = 7.1, SD = 2.9$) than during the native language ($M_{Native} = 6.5, SD = 3.3$). The results show that the native prototype and its variants received fewer sucking responses than the nonnative prototype and its variants. Results also showed an interaction effect of Language Experience and Prototypicality ($F_{1,75} = 4.6, p = .035$) (see Figure 3). To further examine the interaction, planned *t*-tests were conducted. For the 40 infants who heard the native vowel, there was no difference in mean sucks during the prototype vs. the nonprototype ($t_{39} = -1.08, p = .29$). However, for the 40 infants who heard the nonnative vowel, the difference in response to the prototype was significantly greater than the response to the nonprototype ($t_{39} = 2.03, p = .049$).

In the overall ANOVA, the effect of Country was significant ($F_{1,75} = 18.4, p < .001$), with USA mean sucks per stimulus ($M_{USA} = 8.1, SD = 3.0$) greater than Sweden sucks ($M_{Sweden} = 5.4, SD = 2.6$). No other main or interaction effects were significant.

Although there were no significant interaction effects involving Country, a further analysis was undertaken to measure the infants' responses to the native and nonnative prototypes in each of the two language communities. The difference between native and nonnative prototypes was significant in the Sweden infants ($t_{38} = 3.58, p = .001$), but not in the USA infants ($t_{38} = .68, p > .05$). A nonparametric analysis was conducted in which the 17 stimuli were rank ordered for individual infants according to how many sucks they received from the infant with Rank 1 being the stimulus with the highest number of sucks and Rank 17 being the stimulus with the lowest number of sucks from that infant. For the USA nonnative group, 16 of 20 infants had the prototype among ranks 1–8, roughly the top half of the 17 ranks (binomial test, $p < .05$, two-tailed). For the USA native language group, 9 of 20 infants had the prototype in the top eight ranks (binomial test, $p > .05$). The difference between the USA native and nonnative groups was significant (Pearson $\chi^2 = 5.2, p = .024$, two-tailed.)

Discussion

The results of our study support the hypothesis that language experienced *in utero* affects vowel perception. Neonates in the two different language communities responded to vowels in their familiar native language category as though they were equivalent to each other. In contrast, they did not treat vowels in an unfamiliar, nonnative category as equivalent. The infants did this in two ways: 1) they sucked less overall when the sound stream was from their native language, presumably because successive sounds were from the same category and repetitive and 2) they behaved as though the native prototype was equivalent to the other

vowels in the category. The absence of significant interaction effects for Country indicates that responding to native/nonnative vowels and prototype/nonprototype did not differ between the groups from Sweden and the USA. We argue that the difference in response to the native and nonnative vowels can be attributed to prenatal perceptual experience, even though infants had between seven and 75 hours of postnatal exposure to their native language. Our results show that there was no effect of the number of hours of postnatal exposure to ambient language on infant responding to familiar and unfamiliar vowels.

We found that neonates, having heard native vowels many times before birth, sucked less when they were exposed to them after birth and they sucked as much to the native prototype as they did to the native variants. Our interpretation, following the prototype literature, is that experience with native vowels renders the native prototype very similar to its variants (see Bremner, 2011²⁸, for a discussion of face prototypes, and Kuhl, 1991²⁹, for a discussion on prototypes and speech categories). Because the infants have never experienced nonnative vowels in the womb, they perceive them as more distinct from one another. One interesting result is the large difference between sucking responses to the nonnative prototype and its variants. Sucking responses were largest to the nonnative prototype. There are data to suggest that, regardless of experience, vowel prototypes are more salient than nonprototypes³⁰. Our results only show enhanced prototype salience for unfamiliar vowels. Further studies with equivalent methods are needed to examine this difference in results.

Additional studies will be necessary to examine whether the results reported here can be generalised to other vowels and languages. It will be especially interesting to compare newborn perception of vowels that are more extreme with regard to their location in the vowel space (such as the vowels used in the present study), with ones that are less extreme. Data suggest that more extreme vowels are generally more salient for infants³¹.

We found that overall pacifier sucking rates were higher in the USA than in Sweden. This could be due to differences in pre- and perinatal care practices in the two countries, such as rates of neonatal pacifier use, epidural anesthesia and breast-feeding.

These results suggest that birth is not a benchmark that reflects a complete separation between the effects of nature versus those of nurture on infants' perception of the phonetic units of speech. Our results indicate that neonates' perception of speech sounds already reflects some degree of learning. Although technically daunting, research during the foetal period is warranted to provide a complete developmental picture of phonetic perception. The finding also raises questions regarding what sounds are available to the developing fetus, how they are processed by the developing brain and how further experience during development continues to shape perception, both in typically developing children and also clinical populations.

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Key Notes

- Being exposed to ambient language in the womb affects foetal phonetic perception.
- Eighty neonates (mean: 33 hrs since birth) in Sweden and the USA responded differently to vowels sounds, depending on whether they were from their familiar native or an unfamiliar nonnative language.
- The neonates sucked their pacifiers more frequently to activate recordings of unfamiliar nonnative vowel sounds, and the hours that had elapsed since birth had no effect on these rates.

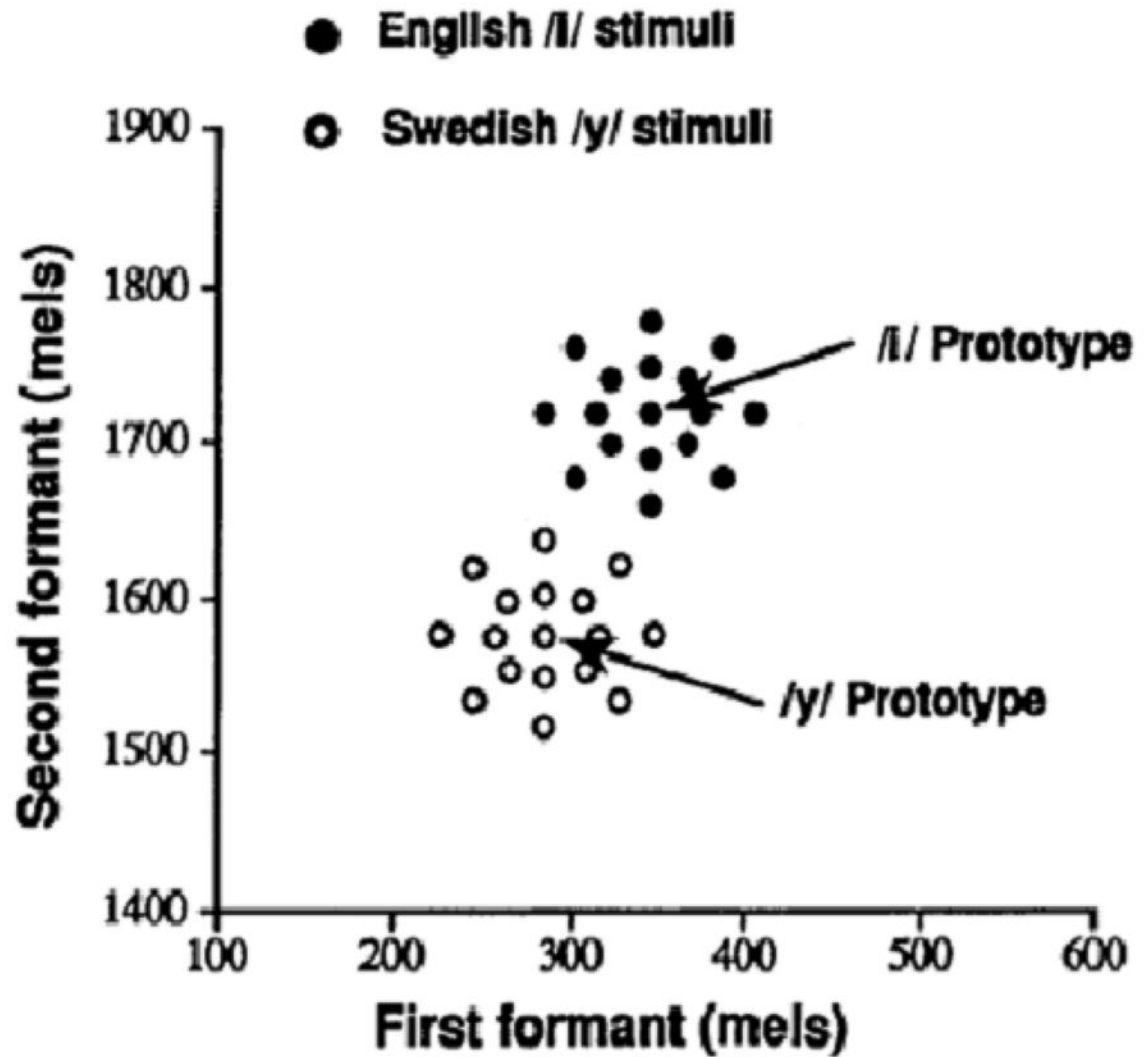


Figure 1. The 17 stimuli for the English vowel /i/ and Swedish /y/ mapped according to their formant frequencies converted to mels which are psychophysical units. The figure is adapted from Kuhl et al, 1992⁹.



Figure 2.
An infant, 20 hours after birth, takes part in the procedure in which hearing speech sounds through headphones is contingent on sucks on a pacifier.

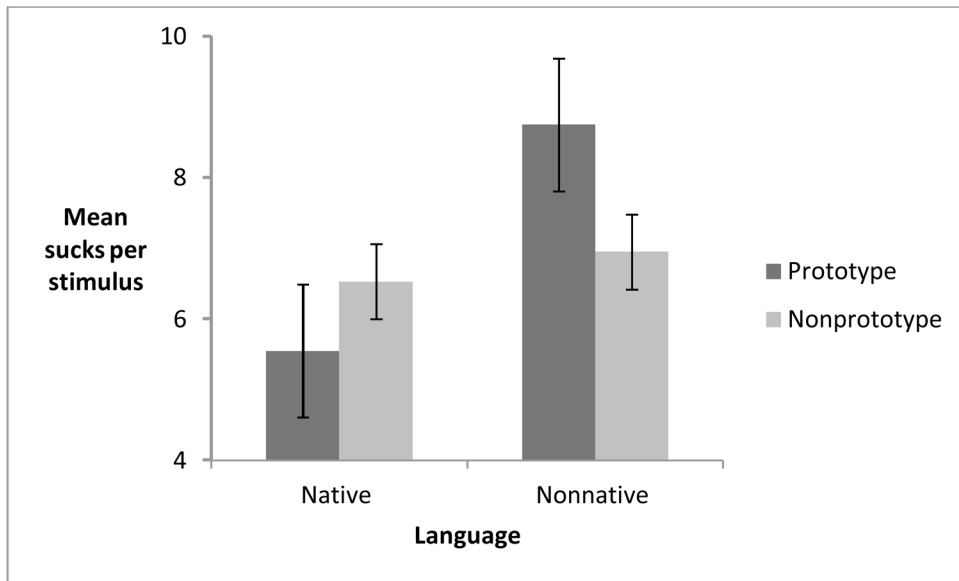


Figure 3. Infant sucking response to contingent auditory presentations of vowels from the familiar native language or the unfamiliar nonnative language. Means represent the mean of sucks that produce the prototype vowel and the means of 16 nonprototype vowels.