DEVELOPMENTAL PATTERNS IN INFANT SPEECH PERCEPTION

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ABSTRACT

This report highlights recent research investigating developmental changes in vowel perception during the first year of life. The findings provide further insights into language-specific influences in infant speech perception and also reveal language-independent perceptual biases that infants bring to the task of vowel perception. Possible interpretations of these findings are discussed and some new research questions are posed.

DEVELOPMENT OF CONSONANT PERCEPTION

Over the past 20 years, researchers have learned a great deal about the development of phonetic perception through cross-language studies of consonant perception. There are now a number of well established findings in this literature regarding the effects of age and language experience. For example, we know that, with few exceptions, young infants (aged 6 months or less) typically show the ability to discriminate both native and non-native consonant contrasts [1,2]. In addition, adults often show difficulty discriminating some non-native consonant contrasts, including contrasts that young infants have successfully discriminated, thus revealing a profound effect of language experience on phonetic perception [3, 4, 5]. It has also been clearly demonstrated that a decline in discrimination of non-native consonant contrasts can be observed as early as 8-10 months of age and is well established by 10-12 months [3, 4, 5, 6]. Studies showing that adults still possess the ability to discriminate non-native consonant contrasts when specific task or stimulus conditions are employed or training is provided, further indicate that declines in discrimination are best interpreted as a reorganization, rather than a loss of perceptual function [7]. Together these findings suggest that in the course of learning a specific language there is a perceptual attunement to the consonant categories of the native language which begins in the first year of life. This perceptual attunement serves to maintain or facilitate the discrimination of native consonant contrasts, but results in a reduced ability to discriminate some, though not all, non-native contrasts.

Two exceptions to the general developmental pattern just described are also informative. First, English infants failed to show a discrimination decline for contrasting non-native phones that English adults could readily discriminate but did not perceive as speech [8]. This suggests that perceptual attunement is evident only for phones that can somehow be assimilated to the native language. Second, infants have shown a decline in discrimination for a non-native contrast that adults readily discriminate [9]. In this case, adults did not perceive either phone to be similar to a specific native phonetic category, but they detected differences between the non-native phones that correspond to a phonemic feature contrast in their native language. This shows that infant attunement to the native language is much less sophisticated that than of adults and reflects a sensitivity to phonetic regularities rather than an ability to process phones according to a system of phonemic contrasts.

CROSS-LANGUAGE STUDIES OF VOWEL PERCEPTION

Recently, research in our lab has investigated developmental changes in cross-language vowel perception during infancy. A general question guiding this research is whether similar patterns of perceptual development are observed for vowels and consonants. This question is relevant because every spoken language is structured using vowels and consonants as segmental units. However, vowels and consonants also differ in their linguistic and communicative functions and in their acoustic properties. To the extent that perceptual attunement to native phonetic categories develops in synchrony across diverse segmental units, similar patterns of development for vowels and consonants are to be expected. In this case, we would expect to observe a decline in discrimination for some non-native vowel contrasts between 6-8 and 10-12 months of age.

To the extent that functional or acoustic factors guide or modulate the development of phonetic perception, it would be expected that vowels and consonants are associated with distinct developmental patterns. With respect to linguistic function, vowels play a more central role than do consonants as carriers of prosodic or suprasegmental information. Moreover, we now know that infants show language-specific responsiveness to some prosodic features of their native language quite early in life, before they evidence language specific attunement in consonant discrimination [10,11]. These abilities imply that, from a every early age, infants deploy considerable attention to vocalic portions of the speech stream. Therefore, linguistic influences on vowel discrimination may become evident earlier in development that they do for consonants. Recent findings reported by Kuhl et al [12] support this hypothesis.

Differences in the acoustic structures of vowels and consonants might also lead to different patterns of perceptual development. Vowels are quite prominent acoustic patterns compared to consonants in that they are typically longer and louder than consonants. Although vowels are typically perceived categorically in more naturalistic conditions (e.g. in syllable context), they are often associated with relatively high levels of within-category discrimination when studied in the categorical perception paradigm [13]. As well, cross-language studies of vowel contrasts in the categorical perception paradigm have shown language-specific effects in identification but not discrimination [14]. These findings suggest that, for acoustic reasons, language-specific attunement might not be evident at the level of vowel contrast discrimination. In this case, we would expect infants not to show a decline in discrimination of non-native contrasts across the first year of life.

Our studies addressing these issues began in Canada with a set of experiments which examined English listeners' discrimination of two German (non-English) vowel contrasts, /y/ vs. /u/ and /U/ vs. /Y/. Multiple natural exemplars produced in a /dVt/ context by a male native German speaker (from Southern Germany) were used as stimuli. The first experiment examined discrimination of these German vowels contrasts by monolingual English-speaking adults and native speakers of German [15]. English adults' discrimination of /dut/ vs. /dyt/ was close to perfect and equal to that of native German adults, revealing no effect of language experience. Discrimination of /dUt/ vs. /dYt/ was better than chance but was also significantly poorer than the German-speaking adults, revealing a small effect of language experience. English adults were also asked to match the German vowels to English vowel categories and rate the quality of the match. These data revealed that English adults perceived German /u/ vs. /y/ and /U/ vs. /Y/ as a good vs. a poor example of similar high back vowels in English (i.e. /u/ and /U/). This corresponds to the category-goodness difference assimilation pattern as described by Best [5]

Next, age-related changes in English-learning infants' ability to discriminate these German vowel contrasts was evaluated in two experiments [16]. The first experiment compared English-learning infants of 6-8 and 10-12 months on their ability to discriminate the two German vowel contrasts in the conditioned headturn procedure. The younger infants were better able to discriminate the non-native contrasts than were the older infants, consistent with previous studies with consonants. However, performance at 6-8 months also fell below levels that have been reported for non-native consonant contrasts which suggested that some decline in discrimination performance was already underway by 6-8 months. This hypothesis was tested in a second experiment in which English infants at 4 and 6 months of age were tested on the two German contrasts using a habituation looking procedure. These data showed that 4 month olds discriminated both German vowel contrasts whereas 6 month olds failed to show evidence of discrimination for either non-native vowel contrast. Both age groups discriminated an English vowel contrast. Thus, the overall pattern of change in infant vowel discrimination across these two experiments was consistent with previous consonant work, indicating a shift from a language-general toward a language-specific pattern during the first year of life. However, our results show this shift to be underway earlier in development for vowels than for consonants.

In a second set of experiments, Ocke Bohn and I attempted to replicate and extend these findings [17]. This research, which was conducted in Montreal, Canada and in Kiel, Germany, was designed to assess the generality of the developmental pattern observed in the first study and to gather more direct evidence for language-specific influences on infant vowel perception. English-learning and German-learning infants at 6-8 and 10-12 months of age were tested on discrimination of an English (non-German) contrast, /dɛt/ vs. /dæt/, and a German (non-English) contrast, /dyt/ vs. /dut/. The English vowels were produced by a native Montreal anglophone. The German vowels were produced by a native German speaker from Northern Germany, a different German dialect from the first study. Identical instrumentation for conducting the headturn instrument was set up in Kiel to test German infants. Data were then collected using identical procedures with English-learning babies in Montreal. Monolingual adults were tested in both cities.

Discrimination of both contrasts was equally good for both German and English adults. Identification and rating data showed that English adults also perceived the German /u/ vs. /y/ as a good vs. poor example of English /u/, however the perceived difference in goodness of fit to English /u/ was larger for this contrast, due to lower ratings of German /y/ in this dialect than in the Southern dialect. For German adults, English /ɛ/ was an acceptable, though not a good, example of German /ɛ/ and English /æ/ was perceived as a poor match to either German /a/ or /ɛ/ or as failing to match any German vowel. This corresponds to the categorizable vs. uncategorizable assimilation pattern as described by Best [5].

Contrary to our expectations, the Kiel babies and Montreal babies did not perform differently on either the German or the English vowel contrast. The 6-8 and 10-12 month olds also did not perform differently in either the Kiel sample or the Montreal sample. Thus, the age-related differences found in the first study were not replicated with a new contrast nor with the same contrast produced in a different dialect. Both age and language groups had greater difficulty discriminating the English contrast than the German contrast. This study showed that infant discrimination accuracy varies for different vowel contrasts, independent of language experience, and does not always change between 6 and 12 months of age.

DEVELOPMENTAL PATTERNS IN INFANT VOWEL PERCEPTION

Overall our findings to date reveal similarities as well as differences in the development of vowel and consonant discrimination. The evidence for an influence of language experience by 6 months shown in our first study is consistent with Kuhl et al's findings of language-specific effects on infant perception of within-vowel category differences [12]. It is interesting that these language-specific effects in vowel perception are evident around the same age that language-specific processing of various aspects of prosodic structure aref foudn, e.g. [11]. This synchrony may be interpreted as evidence of an attentional focus on vocalic information in early infancy. However, further declines between 6-8 and 10-12 months of age show that perceptual attunement for vowels also continues through the later half of the first year, just as has been observed for consonants. That we find both converging and diverging results for vowels and consonants at different ages raises the question of whether a single processing mechanism can account for both the early and later changes in infant vowel discrimination. This issue is discussed further in [18].

As mentioned earlier, previous consonant studies have not always shown there to be a decline in discrimination of a non-native contrast between 6-8 and 10-12 months. We now know that the same observation applies to cross-language vowel discrimination. However, it is interesting to note that, to date, the contrasts which have failed to show a decline, and therefore a language effect, have differed for vowels and consonants with respect to the similarities that adults perceive between the non-native phones and their native language phonetic categories. As outlined in the model proposed by Best [9], such differences can be informative as to the kinds of phonetic regularities that infants begin to detect in the native language with increasing age and language experience.

In the case of consonants, Best has reported on two non-native contrasts, to date, in which no discrimination decline was observed in English-learning infants. One contrast, a Zulu click contrast, was not assimilable to the native language by English adults [8]. The other contrast was the Ethiopian ejective stop contrast, /p'ɛ/ - /t'ɛ/. English adults perceived /p'ɛ/ to be highly similar to English /p/ and /t'ɛ/ to be highly similar to English /t/. All other consonants contrasts that have been tested with infants have shown developmental decline, even when adults could easily discriminate them. These contrasts include a variety of assimilation patterns in adults including 1) a single category mapping in which both non-native phones are perceived as being quite similar to the same native phonetic category, 2) a two category mapping in which each non-native phone is perceived as being similar to a different native phonetic category, and 3) a category goodness difference mapping in which the non-native phones are perceived as good vs. a poor match to the same native phonetic category.

In the case of vowels, we have failed to show a decline for a contrast that was perceived as a category goodness difference (i.e. /u/-/y/ in the Northern dialect). However, this same contrast showed a decline for tokens from a Southern dialect which was associated with a smaller difference in category goodness. In comparison, with consonants, the category goodness assimilation has been consistently associated (so far) with a perceptual decline [9]. The other vowel contrast failing to show any language effects in our work, English /dɛt/ vs. /dæt/ was assimilated by German adults as a categorizable vs. an uncategorizable vowel. To our knowledge, no consonant contrast showing this assimilation pattern has been tested with infants.

Overall, the existing data show that with age and experience infants show some attunement to native vowels in that they ignore some vowel differences that are not meaningful in their native language, provided that the differences correspond to a single native vowel and are sufficiently small, whereas they continue to discriminate other differences that don't convey word meaning in their native language. On the other hand, it seems that infants ignore a wider range of consonant differences that are not functional in the native. They only appear to continue to discriminate consonant differences if they are remarkably similar to (and perhaps indistinguishable from) specific native language phones or when presented phones that are not assimilable to the native language.

Certainly further research is needed before any strong conclusions can be drawn regarding differences in how infant perception of vowels and consonants becomes tuned to the native language. However, patterns in the existing data suggest that we should continue to entertain the hypothesis that language-specific processing is expressed differently in the development of vowel and consonant perception. On the basis of our findings and the language-specific effects demonstrated by Kuhl et al. it could be predicted language experience brings about subtle changes in the structure of vowel categories such that language effects may only be observed for discrimination of non-native vowel contrasts in which both vowels are quite similar to a single native vowel category.

PERCEPTUAL ASYMMETRIES IN INFANT VOWEL PERCEPTION

In our first set of infant experiments we noted very striking directional asymmetries. That is, infants performed differently depending on which direction they were presented a vowel change, which we had varied simply as a matter of experimental control. We became quite interested in these directional asymmetries because they suggested an interesting connection between our work and findings reported by Kuhl et al [12] showing there to be language-specific influences on the internal structure of vowel categories by 6 months of age.

In this work, Kuhl et al started with central /i/ vowel that a group of English adults had rated as being a very good example of English /i/. Additional /i/ vowels were then created by increasing and decreasing F1 and F2 values (in equal mel steps) from this central, prototypic /i / such that the peripherals vowels formed four equally-spaced rings surrounding the central vowel in an F1 by F2 space. Ratings of the peripheral vowels (as an example of English /i/) decreased as distance from the central vowel increased.

In the same way, vowel stimuli were created with a good or prototypic example of Swedish /y/ as the central vowel and four rings of /y/ variants surrounding it. Here also, ratings of the vowels (as examples of Swedish /y/) by Swedish adults decreased as distance from the central vowel increased.

Kuhl et al found that English infants showed poorer performance in discriminating the central English /i/ vowel from the peripheral /i/ vowels surrounding it, compared to their performance in discriminating the central Swedish /y/ from each of the peripheral vowels surrounding it. Swedish infants showed the reverse pattern, i.e. better performance when discriminating the English prototype from it's peripheral variants than when discriminating the Swedish prototype from it's peripheral variants. These data were interpreted as evidence for a language-specific perceptual magnet effect. Essentially, the claim is that, with language experience, a native vowel begins to act like a perceptual magnet which appears to pull more peripheral vowels toward it, thus effectively shrinking the perceptual space surrounding the vowel prototype. The magnet effect enhances perceptual generalization to the prototype and in doing so makes discrimination of differences near the prototype more difficult.

The directional asymmetries that we observed in our first infant study (testing English infants on German /u/-/y/ and /U/ vs. /Y/), were consistent with the notion of a language-specific perceptual magnet effect. As shown in Figure 1 below, among the 6-8 month olds, discrimination was significantly poorer for infants tested with /u/ or /U/ as the reference vowel (i.e. on a vowel change from /u/ to /y/ and from /U/ to /Y/) compared to infants presented the change in the reverse direction. Thus, within each contrast, the back vowel appears to act like a perceptual magnet. Our experiments with English adults showed that German /u/ and /U/ are more typical of English vowels than are /y/ and /Y/ [15]. Thus, within each contrast the vowel which acts like a magnet was the more typical (or English-like) vowel. As such, the directional asymmetries that we observed in infant discrimination of non-native vowel contrast could be taken as further evidence that vowel perception is organized around language-specific prototypes (i.e. "best" or most typical instances) by 6 months of age.

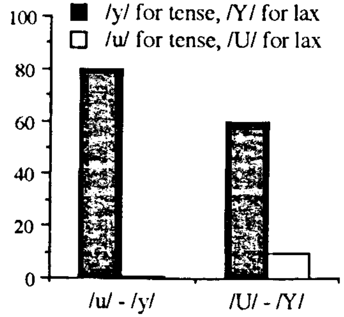

Figure 1. Proportion of English 6-month-olds reaching criterion on German /u/-/y/ and /U/-/Y/ plotted separately for infants tested with different reference vowels.

We designed our second infant study (with German and English infants) to test this hypothesis. If the directional asymmetries indicate a language-specific perceptual magnet effect, we expected to replicate the same directional effect (as shown in first study) for English infants tested on the German contrast and to find no direction effect for German infants tested on the German contrast. In addition, we expected German infants tested on the English contrast to show a direction effect in which /ɛ/ acts like a perceptual magnet. That is, we expected discrimination to be poorer in infants tested with /dɛt/ (the more German-like vowel) compared to those infants tested with /æ/ (the less German-like vowel) as the reference vowel. Likewise, we expected to find no direction effect in the English infants tested on the English vowel contrast.

For the German contrast, /dut/ - /dyt/, the directional asymmetry was replicated and was quite robust. However, as indicated in Figure 2, this asymmetry, showing /u/ to act like a perceptual magnet, was evident in both the English infants and the German infants.

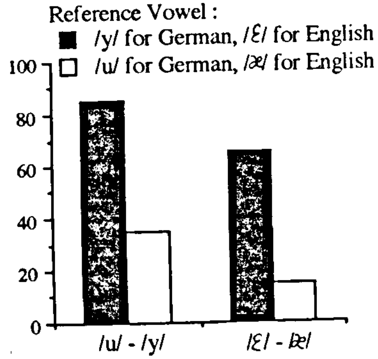

Figure 2. Proportion of infants (across both age and language groups) reaching criterion on English /æ/ - /ɛ/ and German /u/-/y/ plotted separately for infants tested with different reference vowels.

For the English contrast, /dɛt/ vs. /dæt/, we also found a strong directional asymmetry, as shown in Figure 2. However, the asymmetry was in the opposite direction from our prediction, showing poorer discrimination when /æ/ served as the reference compared to when /ɛ/ was the reference vowel. This direction effect, showing /æ/ to act like a perceptual magnet, was also evident in both German and English infants. The direction effect did not interact with age or language experience for either vowel contrasts.

Clearly, the pattern of directional asymmetries in our second study are inconsistent with the notion of a language-specific perceptual magnet effect. These asymmetries also cannot be explained as an effect of markedness because, in the English contrast, the vowel which acts like a perceptual magnet, /æ/, occurs much less frequently across languages compared to /ɛ/. Therefore, these asymmetries point to a language-independent bias that infants bring to the task of vowel perception. The only consistency that we have noted in these asymmetries is that, within each contrast, the vowel which appears to act like perceptual magnet is produced with a more extreme articulatory posture (re vowel height and front-back dimensions). Thus, there appears to be a greater perceptual stability associated with vowels produced with more extreme articulatory postures. Ocke Bohn and I are continuing to test this hypothesis in studies of German vowel contrasts by German infants. So far, we have found an asymmetry associated with German /e/ vs. /I/, which is consistent with our hypothesis. We have also noted asymmetries in other vowel studies with infants and adults which are consistent with this interpretation (see [17]).

Overall, several clear conclusions can be drawn regarding perceptual asymmetries. First, the direction of a perceptual asymmetry is not language-specific, but is an default, language-independent perceptual bias. Second, these directional effects are quite robust in infants, whereas in adults we have found little or no evidence for these asymmetries using similar testing procedures. Given these age differences, it is reasonable to predict that the magnitude of a directional effect may be altered by language experience. Our current data fail to provide a good test of this prediction.

At present there are more questions than answers surrounding the significance of these perceptual asymmetries. One possibility that we are currently considering is that these asymmetries reflect the operation of mechanisms involved in normalization for talker differences. The corner vowels in a traditional vowel space, which correspond to extreme articulatory postures, define constraints placed on vowel productions by the size and shape of the vocal tract. These corner vowels, especially /i/ and /u/, have been shown to be particularly stable in that large deviations in articulation are associated with small changes in formant frequency [19]. Basic research in vowel perception has also suggested that the corner vowels, which are less likely to overlap acoustically with other vowels, might provide particularly clear cues to vocal tract size [20]. While adults are likely to employ a wide range of information in calibrating for different talkers, infants might rely on a more restricted set of cues in vowel normalization. Thus, the enhanced perceptual stability of more extreme vowels might reflect their reliance on particular vowel cues in calibrating for differences in vocal tract size. There are also some interesting changes in infants vowel production in the first year of life which suggest that extreme vowels play a special role in the infant's mapping of the vowel space. See [21] for a review and discuss of this work.

In future research, we will address three questions to further clarify the meaning of perceptual asymmetries. First, are there latent asymmetries in adult cross-language vowel discrimination that will become evident under test conditions which preclude ceiling performance levels? There was, in fact, a small direction effect, in the same direction as shown by the infants, in English adults' discrimination of the German /dUt/ vs. /dYt/ contrast. Our expectation is that we will be able to show directional asymmetries in adults for the other non-native vowel contrasts, either in reaction measures or in a dual task paradigm which lowers overall discrimination accuracy. This would suggest that these asymmetries reflect an inherent phonetic bias that becomes weaker, but is not lost, with age.

If asymmetries are evident in adults as well as infants, it will then be interesting to ask whether such asymmetries reflect a species-specific perceptual bias. To the extent that these asymmetries reflect auditory processing constraints, we would expect animals that possess a similar auditory system to show the same patterns. On the other hand, if an appropriate animal failed to show perceptual asymmetries, it would suggest that the directional effects are showing a phonetic bias that, perhaps, reflects a sensitivity to vocal tract constraints.

Finally, it will be also useful to explore the conditions which generate these directional effects by using other stimulus sets. For example, it will be informative to determine whether directional effects are found only in discrimination of vowels that specify a single talker. If this were the case, it would increase support for the hypothesis the biases evident in directional asymmetries reflect mechanisms used in mapping a specific talker's vowel space. Alternatively, it is possible that directional asymmetries might be also be observed in discriminating a vowel contrast in productions from multiple talkers. This outcome would imply that these perceptual tendencies may potentially contribute to the development of talker-independent phonetic categorization skills.

SUMMARY

Overall, studies to date point to similarities as well as difference in the development of vowel and consonant perception. However, a great deal more research is needed to arrive at a comprehensive understanding of the development of infant phonetic processing abilities. On the basis of our present findings and related studies, it appears that effects of language experience on a vowel perception are subtle and occur against a background of strong language-independent perceptual biases. Future research should strive to clarify the contribution of inherent perceptual biases and language-specific influences in the development of phonetic perception. With this knowledge, we can begin to explore the significance of these developmental changes in the child's acquisition of word meaning.

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