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Asymmetries in vowel perception

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Abstract

Asymmetries in vowel perception occur such that discrimination of a vowel change presented in one direction is easier compared to the same change presented in the reverse direction. Although such effects have been repeatedly reported in the literature there has been little effort to explain when or why they occur. We review studies that report asymmetries in vowel perception in infants and propose that these data indicate that babies are predisposed to respond differently to vowels that occupy different positions in the articulatory/acoustic vowel space (defined by F1–F2) such that the more peripheral vowel within a contrast serves as a reference or perceptual anchor. As such, these asymmetries reveal a language-universal perceptual bias that infants bring to the task of vowel discrimination. We present some new data that support our peripherality hypothesis and then compare the data on asymmetries in human infants with findings obtained with birds and cats. This comparison suggests that asymmetries evident in humans are unlikely to reflect general auditory mechanisms. Several important directions for further research are outlined and some potential implications of these asymmetries for understanding speech development are discussed.

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1. Introduction

In a review of research on categorization Medin and Barsalou (1987) state: “reference points are extremely important for both [sensory perception and generic knowledge] category types and probably for all category types. Reference points can be either salient values on dimensions that structure categories or prototypes that contain characteristic and ideal attributes of a category”. Following this definition, Medin and Barsalou identify several consequences of reference points that serve as a

means by which we can identify them. One of the consequences of reference points described by Medin and Barsalou are asymmetrical similarity relations, i.e. prominent differences in perceived similarity for a stimulus pair that emerge when the order of reference and comparison stimulus are switched. According to these authors, asymmetries often mark important reference points that deserve closer investigation.

Asymmetrical relations contradict the basic assumption of symmetry that characterizes a Euclidean space. Perhaps because perceptual spaces have been assumed to be Euclidean (see Shepard, 1974) the assumption of symmetry was quite unchallenged in studies of perceptual relations at least until the mid-70s. As noted by Terbeek (1977) and Tversky and Gati (1978), violations of symmetry

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(for instance in perceptual confusions, where A is confused more frequently with B than B is with A, (see Miller and Nicely, 1955)) were commonly attributed to and analyzed away as response bias. However, studies which uncovered asymmetrical perceptual relations in a number of stimulus domains such as color, line orientation, and numbers (Rosch, 1975a), as well as geometric figures and country concepts (Tversky and Gati, 1978) strongly suggest that perceptual asymmetries may provide an important key to understanding the nature and structure of perceptual spaces. Converging evidence from these studies suggests that perceptual asymmetries exist because stimuli in a perceptual domain are not equally salient (i.e., intense, frequent, familiar, “good”, informationally rich). Serious consideration of perceptual asymmetries in the stimulus domains studied by Rosch (1975a,b) and Tversky and Gati (1978) has played an important role in the formulation of hypotheses and models of the mental lexicon and of similarity relations in general (see Rosch, 1975a; Rosch and Mervis, 1975; Tversky, 1977).

The main point to be made in this paper is that perceptual asymmetries in vowel perception, although well documented, have not received the attention that they deserve. In Section 2 of this paper we advance this position by showing that the literature provides many examples of asymmetries that, to our knowledge, can only be explained by considering the location of the contrasting vowels within the articulatory/acoustic vowel space.¹ From this we propose that this consistent bias indicates that peripheral vowels may serve as important perceptual reference points for human listeners. In Section 3, we raise several questions about vowel perception asymmetries that, if fully answered, will bring us closer to an understanding of the nature of these effects, what gives rise to them, and what acts to reduce them. This will include a comparison of asymmetries observed in vowel discrimination in infants and several non-human animals which suggest that these patterns

may be species-specific. In Section 4, we consider the potential significance of the specific bias that we have observed, and suggest some further research to illuminate the role of peripheral vowels in the development of vowel processing.

2. Asymmetries in infant vowel perception

Our interest in perceptual asymmetries was first raised by the results of a study that was designed to examine age and language effects in infant vowel perception. In this study, Polka and Werker (1994) tested discrimination of the German /u/–/y/ and /ɔ/–/ʏ/ contrasts by English-learning infants’ in two age groups: 6–8 and 10–12 months. As is customary in the change/no change procedure used by Polka and Werker, presentation of each contrast was counterbalanced, such that one half of each infant age group was presented with one direction of change, e.g. for /u/ versus /y/, half were presented a change from /u/ to /y/, and half were presented a changed from /y/ to /u/. Results revealed a robust effect of order of presentation, with both 6–8 and 10–12 months olds performing better when the direction of change was from /y/ to /u/ (rather than from /u/ to /y/), and when the direction of change was from /ʏ/ to /ɔ/ (rather than from /ɔ/ to /ʏ/). Polka and Werker reported that these perceptual asymmetries were consistent with the perceptual magnet effect previously observed in infant and adult within-category vowel discrimination as described by Kuhl (1991) and Kuhl et al. (1992) in that the more native-like vowel appears to act as a perceptual magnet. This interpretation was compelling given English adults’ identification and rating of the German vowel stimuli; these data show that each vowel pair was perceived as a good versus poor example of the same English vowel. Specifically, German /u/ and /y/ were perceived as a good versus poor instance of English /u/, respectively, and German /ɔ/ and /ʏ/ was perceived as a good versus poor instance of English /ɔ/, respectively (Polka, 1995).

A subsequent study by Polka and Bohn (1996) provided a direct test of this hypothesis that perceptual asymmetries in infant vowel perception are due to the relatively more familiar vowels acting as

¹ It should be noted that perceptual asymmetries have also been discussed by Miller and Eimas (1996) with respect to the perception of voicing categories.

perceptual magnets. In this study, we examined the discriminability of the English (non-German) /*ɛ*/–/*æ*/ contrast and the German (non-English) /*u*/–/*y*/ contrast by 6–8 and 10–12 month-old German- and English-learning infants.² We expected to observe perceptual asymmetries in discrimination of the non-native but not native contrasts. This prediction was not supported. Instead, for German /*u*/–/*y*/, both German and English infants at both ages showed the same perceptual asymmetry as found by Polka and Werker (1994), with the /*y*/ to /*u*/ change being more discriminable than the /*u*/ to /*y*/ change. For the English /*æ*/–/*ɛ*/ contrast, discrimination was clearly easier if the change occurred from /*ɛ*/ to /*æ*/ than when it occurred from /*æ*/ to /*ɛ*/, irrespective of the age and the language background of the infants. For both contrasts, the asymmetries were quite prominent and did not interact with age or language. Note that, contradictory to predictions generated from the perceptual magnet effect, the English /*æ*/ vowel (which has no direct counterpart in German) acted as a reference vowel for both English- and German-learning infants. Rather than supporting the native language familiarity hypothesis, the asymmetries uncovered in this direct comparison of English versus German-learning babies revealed a language-universal bias.

The three contrasts for which we found asymmetries, /*u*/–/*y*/, /*ɛ*/–/*æ*/ and /*ɔ*/–/*ʌ*/, are plotted in an F1–F2 vowel space in Fig. 1(a) along with several other vowel contrasts for which asymmetries have been observed in human subjects (discussed below); for each contrast the direction in which discrimination was easier, hence the arrows point to the more salient or reference vowel for each contrast. What might account for these effects? Several possibilities can be ruled out. First, they cannot be explained by considering only the phonological status of the vowels in the infants' native language and thus are inconsistent

Fig. 1. Plot of F1/F2 frequencies for contrasts showing asymmetries in vowel discrimination with arrows pointing to the reference vowel for the contrast; vowel changes in this direction were easier to discriminate. Infant data (a—above); animal data (b—below): blackbirds (solid lines only), cats (solid and dashed lines). Formant frequency values are approximate.

with the notion of native language magnets. Second, these asymmetries cannot be fully explained as a perceptual attraction for vowels that are favored across linguistic inventories. For /*y*/–/*u*/ and for /*ʌ*/–/*ɔ*/, the easier direction of change was going from a less common to a more common vowel; however the reverse pattern was observed for /*ɛ*/–/*æ*/ given that /*æ*/ is clearly less common than /*ɛ*/. Third, neither amplitude nor duration differences between the contrasting vowels can explain these directional effects, because the tokens in the /*u*/–/*y*/,

² The /*u*/ and /*y*/ vowels used in this study were produced by a speaker of North German whereas the stimuli used in (Polka and Werker, 1994) were productions by a South German speaker; the formant differences between /*u*/ and /*y*/ were larger for the North German tokens.

/u/–/ʏ/ and /e/ and /æ/ contrasts were selected so that these dimensions had overlapping values and, in the case of /e/ and /æ/, the naturally present duration contrast was digitally neutralized (Polka and Bohn, 1996; Polka, 1995). Fourth, as shown in Fig. 1(a), it is also not possible to explain these asymmetries by simply noting the direction of change in either F1 or F2 alone. But what is it about the vowels /u/ (in the /u/–/ʏ/ contrast), /o/ (in the /o/–/ʊ/ contrast), and /æ/ (in the /æ/–/e/ contrast) that makes them more salient? As shown in Fig. 1(a), each of these vowel asymmetries can be accounted for by considering the location of each vowel within a traditional articulatory or F1/F2 acoustic vowel space.³ That is, vowel discrimination is easier for infants when they were presented a change from a less peripheral to a more peripheral vowel (closer to the limits or corner of the vowel space). Thus, we conclude that the perceptual asymmetries point to a language-universal perceptual bias that infants bring to the task of vowel discrimination such that the relatively more peripheral vowel in a contrast serves as a reference vowel. The perceptual asymmetries observed in both studies (Polka and Werker, 1994; Polka and Bohn, 1996) are consistent with this hypothesis.

We created an opportunity to test this hypothesis further in a recent infant vowel perception study (Bohn and Polka, 2001). The primary goal of this study was to examine the role of target spectral, dynamic spectral, and duration cues in German-learning infants' discrimination of several native vowel contrasts presented in a /d/ + vowel + /t/ syllable. Discrimination of three

German contrasts, /i/–/e/, /e/–/ɪ/ and /o/–/ʊ/, was examined in a between-subjects design using the conditioned headturn procedure. Every infant was tested in several stimulus conditions beginning with an unedited full cue condition. Each infant had to reach a pre-set level of discrimination accuracy on these unmodified syllables in order to continue in the experiment. For each contrast we tested infants until 20 succeeded in the full cue condition, 10 in each direction of vowel change. Based on our peripherality hypothesis, we predicted that we would need to test more babies to get 10 who reach criterion when the direction of change was from the relatively more peripheral vowel to the less peripheral vowel. Specifically, we expected that /i/ would act as a reference vowel in the presentation of the /i/–/e/ contrast, that /e/ would act as the reference vowel in the presentation of the /e/–/ɪ/ contrast, and that /o/ would act as the reference vowel in the presentation of the /o/–/ʊ/ contrast. These three contrasts are also plotted on Fig. 1(a).

Overall, when presented a vowel change from a more peripheral to the less peripheral vowel, 80 infants had to be tested to get 30 (10 per contrast) to reach the pre-set criterion. In comparison, when the direction of change was from a less peripheral to a more peripheral vowel, only 52 infants had to be tested to get 30 (10 per contrast) to reach criterion.⁴ Chi-squares computed on these data showed that the proportion of infants reaching criterion differed significantly as a function of the direction of change ($\chi^2 = 4.604$, $p < 0.05$). Separate chi-squares were also conducted for each contrast. The results revealed a significant effect of direction of change for the /e/–/ɪ/ contrast ($\chi^2 = 6.39$, $p < 0.05$); as predicted, more infants had to be tested in the /e/ to /ɪ/ direction (34 tested to get 10 reaching criterion) than in the /ɪ/ to /e/ direction (15 tested to get 10 reaching criterion). The chi-squares did not reach significance for the other two contrasts, although the differences noted were in

³ In articulatory terms, the vowel space is defined by the extreme positions that the human vocal tract can assume in vowel production and the corresponding vowel qualities: the vowel [i], in which the tongue is maximally high and front, and the vowel [ɒ], in which the tongue is maximally low and back. All other vowel qualities are described in relation to these extreme vowels (see Handbook of the IPA, 1999). The acoustic vowel space is defined by the acoustic consequences of extreme vowel articulations within a two-dimensional space defined by F1 (corresponding to differences in vowel height) and F2 (corresponding to differences in the front–back dimension). Within this acoustic space, [i] has the lowest F1 and the highest F2 values, and [ɒ] has the highest F1 value and an F2 value that is maximally close to F1 (see Ladefoged, 2001).

⁴ Infants who did not reach criterion on the test contrast were immediately tested on an easier /i/–/a/ contrast. Infants who failed to discriminate this contrast were considered unwilling to perform in the task and were removed from ALL analyses.

the predicted direction. Specifically, more babies had to be tested in the /i/ to /e/ direction (25 tested to get 10 reaching criterion) than in the /e/ to /i/ direction (18 tested to get 10 reaching criterion); more babies were tested in the /o/ to /ɔ/ direction (21 tested to get 10 reaching criterion) than in the /ɔ/ to /o/ direction (19 tested to get 10 reaching criterion). It is interesting to note that the formant differences for these two contrasts, /o/-/ɔ/ and /i/-/e/, are smaller compared to the other contrasts that showed clearer asymmetries.

We also turned to the literature for other reports on asymmetries to test our hypothesis. Vowel contrasts showing asymmetries in the literature are included in Fig. 1(a) and are also listed with specific references in Table 1. We found several infant studies in which significant direction effects were observed, and, in almost every case, the asymmetry reported upheld our hypothesis. Swoboda et al. (1978) examined the discrimination of brief (60 ms) synthetic vowels along an /i/-/ɪ/ continuum by 8-week-old English learning infants and reported that stimulus shifts in the direction of the more peripheral vowel /i/ were discriminated better than changes toward the less peripheral vowel /ɪ/. These same researchers observed a non-significant trend in the same direction in an earlier infant study in which longer (240 ms) vowels were used (Swoboda et al., 1976). The same directional asymmetry in the discrimination of synthetic /i/-/ɪ/ vowels was also observed in a more recent study by Dejardins and Trainor (1998). Using natural speech, Best et al. (1997) also found asymmetries when they examined discrimination of the Norwegian vowel contrast /y/-/ʉ/ (high front out-rounded versus in-rounded) in English-learning infants at three ages: 3–5, 6–8 and 10–12 months. The youngest age group showed an asymmetry in the expected direction, with a change from /ʉ/ to /y/ being more discriminable than a change from /y/ to /ʉ/. The 6–8 month old infants in the Best et al. study showed no asymmetry, and the oldest age group failed to discriminate the Norwegian contrast.

To date we have come across only one infant study in which an asymmetry was found that our hypothesis, as currently formulated, fails to predict. Best and Faber (2000) also examined the

Table 1

Studies of human infants and of animals that have reported asymmetries in vowel discrimination

Study	Infants' ambient language	Contrast
<i>(a) Human infants</i>		
Polka and Werker (1994)	English	y → u ʏ → ʊ
Polka and Bohn (1996)	English	y → u ɛ → æ
Bohn and Polka (2001)	German	y → u ɛ → æ
	German	ɪ → e (e → i) (ʊ → o) (ɪ → i)
Swoboda et al. (1976)	English	ɪ → i
Swoboda et al. (1978)	English	ɪ → i
Dejardins and Trainor (1998)	English	ɪ → i
Best et al. (1997)	English	ʉ → y
Best and Faber (2000)	English	i → y
<i>(b) Animals</i>		
Hienz et al. (1981)	Blackbirds	ɔ → æ ɔ → ɑ ɔ → ɛ ɑ → æ
Hienz et al. (1996)	Cats	ɔ → æ ɔ → a ɔ → ɛ ɑ → æ ʊ → ɛ ʊ → æ ʊ → ɑ

Arrows show the direction in which discrimination was easier. Parentheses indicate non-significant trends for the contrasts listed.

discrimination of Norwegian /i/-/y/ (high front unrounded versus out-rounded) by English-learning infants at 3–5, 6–8 and 10–12 months, using natural speech. They found that the youngest age group discriminated the contrast in the /i/ to /y/ direction, but not in the /y/ to /i/ direction. (The 6–8 month olds failed to discriminate in either direction, and the 10–12 months olds discriminated in both directions.) This asymmetry is not predicted by our hypothesis because Norwegian /i/ and /y/ are equally peripheral in an F1–F2 vowel space; they differ only with respect to F3 frequency. Thus, it seems that, for this contrast, F1

and F2 are inadequate for describing a difference in peripherality.⁵ Best and Faber suggest a modification of our hypothesis, in which peripherality is defined in terms of both tongue position and lip configuration.⁶

It is noteworthy that asymmetries consistent with our peripherality hypothesis are also evident when English adults are tested on discrimination of native contrasts. This includes work reported by Repp et al. (1979) on an /i/–/ɪ/–/e/ series, Cowan and Morse (1986) on an /i/–/ɪ/ series, Repp and Crowder (1990) using variants of 8 vowels, and research reported by Grieser and Kuhl (1989), Iverson and Kuhl (1995) and Sussman and Lauckner-Morano (1995), each of which examined a set of /i/ variants. Most of these studies focused on vowels from the high front region of the vowel space and all of them were conducted using isolated synthetic vowel stimuli. It is also worth noting that these adult studies involve standard AX and AXB discrimination tasks, which indicates that asymmetries are not a simple artifact of the repeating stimulus presentation format used in infant studies.

In summary, directional asymmetries appear in vowel discrimination in both infants and adults. Taken together, we have noted that these patterns are not fully explained by reference to native vowel inventories (i.e., reference vowels are not necessarily found in the infants' ambient language), to universally favored vowels, to simple effects of duration or amplitude, or to the direction of change of a single formant. It seems that infants are predisposed to respond differently to vowels that occupy different positions in the articulatory/acoustic vowel space (defined by F1–F2) and that the directional asymmetries point to a universal bias that infants bring to the task of vowel perception.

3. Questions raised

The findings described above raise several issues that must be addressed to fully understand this bias in infant vowel perception. First, do these asymmetries simply reflect some inherent processing biases of our auditory mechanisms? In other words, perhaps differences in acoustic salience for vowels are directly tied to extremes of the vowel space. If so, there should be some consistency in the direction effects observed across species with similar peripheral auditory systems. Direction effects reported in two animal studies of vowel perception seem to suggest that this is not the case. Hienz et al. (1981) examined the discriminability of contrasts involving the vowels [æ], [ɔ], [ɑ] and [e] in blackbirds and in pigeons. Blackbirds, but not pigeons, showed perceptual asymmetries in the discrimination of the contrasts [æ]–[ɔ], [ɑ]–[ɔ], [ɔ]–[e] and [æ]–[ɑ]. Hienz et al. (1996) also examined vowel discrimination in cats using a larger set of vowels, including those used in the Hienz et al. (1981) study, plus [o]. As illustrated in Fig. 1(b), these asymmetries suggest that for cats and birds increases in F2 and F1 frequency are easier to detect than decreases. The only exception to this pattern is /e/–/æ/ which is unclear because it involves both a downward shift in F1 and upward shift in F2. In comparison, as shown in Fig. 1(a), a simple downward or upward shift in F1 or F2 cannot account for the asymmetries observed in infants. Rather, infants appear to perceive shifts toward the periphery of this two-dimensional space more readily than shifts toward the center.

We are not aware of studies that have reported asymmetries in vowel perception of animals whose auditory system is more similar to the human auditory system than that of cats and blackbirds. With this reservation in mind, the animal data from the Hienz et al. studies suggest that the particular asymmetries that we have observed in human vowel perception are species-specific. However, a more direct comparison of human newborns and animals using identical stimuli and comparable procedures is needed to confirm this claim. If newborns show asymmetries that animals do not, then we can more firmly conclude that peripheral vowels have a special status in human

⁵ This contrast is not plotted on Fig. 1(a) because these vowels overlap in F1–F2 space.

⁶ It is worth noting that /y/ appears to be the reference vowel within both Norwegian contrasts studied by Best and colleagues, i.e. for /y/–/i/ and for /y/–/u/.

perception, perhaps pointing to mechanisms that link vowel perception and production processes.

Asymmetries in vowel perception may reflect an innate bias in humans. However, it is also conceivable that this bias is the result of exposure to speech and thus arises from the exposure to vowels that infants experience beginning at birth, or just before. This is a strong possibility given that nearly all language inventories include /i/, /a/ and /u/ (Lindblom, 1986) and that vowel information is clearly emphasized in speech directed to infants. A general emphasis is evident in the elongation of vowels that occurs in infant-directed speech (Fernald, 1984; Papousek et al., 1985). In addition, data reported by Bernstein Ratner (1984) show that the peripheral vowels, /i/, /a/, /u/ and /æ/, are clarified in speech directed to pre-linguistic infants, such that these vowels are produced with little or no acoustic overlap with other vowels. Kuhl et al. (1997) showed that the vowel space defined by /i/, /a/ and /u/ is expanded in speech directed to 6-month olds such that these corner vowels occur in a hyperarticulated form (other vowels were not analyzed); this was observed regardless of whether mothers were speaking English, Swedish or Russian. Presently, two months is the youngest age at which we have evidence for asymmetries in human vowel perception (Swoboda et al., 1978). Since asymmetries have not been examined in newborns it is unclear whether these patterns require some exposure to speech to appear. If neither newborns nor non-human animals demonstrate asymmetries, it would be very interesting to see if exposure to speech leads to emergence of these patterns in human as well as non-human animals.

The effect of age and language learning on these asymmetries is another issue yet to be fully explored. Are asymmetries maintained later in development for vowel contrasts that do not become functional in the listener's native language? Likewise, are these patterns attenuated if the native language codes the contrast as meaningful? Asymmetries observed for some non-native contrasts seem to appear only very early in development (e.g. Best et al., 1997; Best and Faber, 2000) whereas other contrasts elicit robust asymmetries in older infants (e.g. Polka and Werker, 1994; Polka and Bohn, 1996). As mentioned above,

some asymmetries are also observed when adults are tested on native contrasts (e.g. Repp et al., 1979; Cowan and Morse, 1986).

Presently, it is not possible to draw any firm conclusions regarding development of vowel asymmetries because the data are quite limited, involve different contrasts and stimulus materials, and were obtained using very different test procedures. We speculate that the vowel perception asymmetries observed in infants are language-universal biases that are either present at birth or emerge quite early in development in response to global, language-universal, aspects of speech. Our view is that experience listening to one's native language then serves to fine-tune these initial biases such that asymmetries will be maintained, further enhanced or reduced in accordance with the structure of native vowel categories. For example, if the referent vowel occurs in the native language but the non-referent vowel does not, the asymmetry is likely to be maintained or enhanced whereas if the referent and non-referent vowels form a phonemic contrast in the native language, the asymmetry will be reduced in mature perceivers. As such, effects of language exposure on these initial biases may result in differences in discriminability of within category variation as shown in the perceptual magnet effect reported by Kuhl et al. (1992). Thus, from our perspective, the native language magnet effects described by Kuhl arise because exposure to different languages alters these language-universal biases to different degrees. It should be noted that both of these effects, a language-universal bias and a language-specific difference in degree of asymmetry, may be observed concurrently, the former as a main effect and the latter as an interaction due to group differences in magnitude of the universal bias. In other words, our claim is that vowel perception is innately structured such that some vowels are, from the start, perceptually more salient and stable relative to others, i.e. exist as "natural perceptual magnets". Language effects are formed against this default structure to form "native language magnets". If this view is correct, then it would seem important to fully describe this default structure, rather than assume that vowel perception is unstructured, and then assess how exposure to

different languages alters the default structure over the course of development. However, to fully isolate language-universal and language-specific patterns we also need to clarify the role of several factors that are likely to contribute to the magnitude of perceptual asymmetries. Specifically, we need to know how much acoustic difference is needed to produce an asymmetry, whether asymmetries are more prominent in perception of synthetic isolated vowels than in natural coarticulated vowels, and in what ways these asymmetries are task-dependent.

Although there are many unanswered questions, a series of experiments conducted by Sundara et al. (in preparation) provides some insights into how asymmetries are affected by language experience and task demands. In this work, English and German adults were tested on the German /u/–/y/ and /ɔ/–/ʏ/ contrasts using a discrimination task similar to that used with infants. The results show that direction effects can be observed in discrimination of natural speech in non-native adult listeners. Moreover, these effects can be observed in response to a single pair of syllables, and also persist when the listener is required to respond to vowels produced by different talkers. Two factors appear to reduce these effects in adults, (1) reducing the ISI in the test procedure and thus reducing demands on auditory memory (see also Cowan and Morse, 1986), and (2) being a native speaker of the language in which in the vowel contrast is phonemic. Additional work of this kind is needed to determine whether these findings hold for other contrasts.

4. Perceptual asymmetries and functional significance

It is encouraging to be able to predict asymmetries and interesting to consider when and why they occur. However, the most exciting aspect of these data is the challenge to define their role in speech development. To broaden the motivation for this discussion it is worth noting some other findings that ascribe unique properties to peripheral vowels. The importance of peripheral vowels is implicit in the fact that these extreme vowels

define the limits in our most fundamental descriptions of vowels as occupying a space defined by the corresponding articulatory/acoustic dimensions of vowel height (F1) and front/back (F2). Formant frequencies for the more peripheral vowels, especially /i/, show less acoustic overlap across tokens produced by different talkers compared to other vowels. Identification results also show lower confusion rates for the point vowels /i/ and /u/ compared to more central vowels (Peterson and Barney, 1952). Liberman (1984) and Nearey (1978) have claimed that certain peripheral vowels, specifically /i/ and /u/, may act as anchors for vocal tract normalization. Moreover, recent data suggest that adult memory for a specific vowel is encoded in a hyperarticulated (i.e. more peripheral) form (Johnson et al., 1993). A quantal articulatory/acoustic relationship has been described only for several peripheral vowels (Stevens, 1989).

Clearly there are multiple lines of work pointing toward unique structural and perceptual properties associated with more peripheral vowels. As such, it is not surprising that some fundamental perceptual skills have been documented using these vowels. For example, we know that infants can form perceptual equivalence classes for vowels produced by different talkers. This was demonstrated in English infants' discrimination of English /i/ versus /a/ (Kuhl, 1979; Marean et al., 1992) and /a/ versus /ɔ/ (Kuhl, 1983), two contrasts involving at least one peripheral vowel. The enhanced perceptual salience and stability of more peripheral vowels may facilitate the formation of language-specific vowel categories. If so, then language-specific tuning may emerge developmentally from the periphery of the vowel space to the interior. Current data documenting language-specific patterns of vowel perception in infants pertain to vowel categories or contrasts that fall close to the limits of the vowel space (Kuhl et al., 1992; Polka and Werker, 1994). Further research exploring developmental changes in perception for more diverse vowel contrasts is needed to identify any global trends in development (see also Lacerda, 1993). A privileged perceptual status with respect to more peripheral vowels may be observed when infant recognition of native vowel categories

is assessed in more demanding tasks, such as segmentation of words from running speech.

The apparent salience of peripheral vowels may also allow them to serve as stable perceptual targets that guide infants in their production of vowels. The first vowel productions of infants are central vowels resulting from an open and neutral posture of the vocal tract. As production skills advance, vowel qualities become increasingly more varied and include more peripheral vowels, so that developmentally the vowel space expands toward the periphery (Kent and Murray, 1982). The emergence of a complete vowel space can be compromised by the presence of hearing loss. Acoustic analyses of speech produced by hearing-impaired babies show that their vowels fail to show the full range of formant frequency differences observed in normal hearing babies, especially with respect to F2 (Kent et al., 1987). This is also evident in babies who experience fluctuating hearing loss due to otitis media (Rvachew et al., 1996). Thus, the emergence of these vowel production skills involves not just anatomical and motor maturation, but also depends on the infant's ability to perceive a full range of vowel qualities. A study by Kuhl and Meltzoff (1996) strengthens this conclusion by showing that 6-month-olds can modify their vowel productions in response to a short-term speech exposure. They found that infants who were exposed to repetitions of the vowel /i/ produced more /i/-like productions. Infants exposed to /u/ productions produced more /u/-like productions and likewise for /a/. These findings clearly show that infants can use their perception of specific vowel qualities to guide their articulatory behavior. We do not know whether the ability to link perceptual and production behaviors is enhanced for certain vowels, such that it emerges first with respect to the most peripheral vowels. Kuhl and Meltzoff (1996) claim that there are innate neural structures that serve to link perception and production processes. Evidence for perceptual asymmetries in newborns but not in non-human animals would support this position.

As a third possibility we propose that vowel asymmetries may be implicated in the infant's ability to perceptually distinguish function and

content words. In English, vowels occurring in function words are more centralized compared to vowels occurring in content words (Morgan et al., 1996; Cutler, 1993). Using English stimuli, Shi et al. (1999) found that newborns could perceptually distinguish these word types. However, in a later study discrimination of this difference (using a habituation paradigm) was found to be asymmetrical in English-learning 6-month-olds, i.e. at this age, babies discriminated a change from function to content words, but not a change from content to function words (Shi and Werker, 2001). This asymmetry mirrors our findings with respect to vowel asymmetries, i.e. discrimination was better when infants were presented a change from words with less peripheral to more peripheral vowels. Shi and Werker explain this asymmetry as being due to English-learning 6-month-olds preference to listen to content words over function words, which they also demonstrate in this study. Are the vowel asymmetries that we have observed important in establishing this preference, or are they simply another manifestation of it? Shi et al. (1999) argue that there is no single acoustic dimension on which this basic grammatical classification can be based and propose that infants perceptually sort these word types by responding differentially to a set of correlated cues. Nevertheless, there may be acoustic dimensions that carry more weight in the initial perceptual sorting of these basic forms and thus are more directly implicated in bootstrapping the infant into this grammatical distinction. Cutler (1993) has argued that vowel quality is an important cue underlying this distinction in English given that vowel quality is an absolute property of strong syllables accessible during on-line processing whereas other cues require recognition of relational differences or statistical properties of the input. It would be useful to examine whether removing differences in vowel quality has a greater impact on infant discrimination of these word types compared to removing other dimensions of difference, such as duration or syllable shape. A more detailed picture of the ontogeny of the asymmetries in vowel discrimination and the emergence of preference for content words would also help delineate the relationship between these findings.

5. Summary

The main goal of this paper was to present evidence for perceptual asymmetries that point to an underlying bias in vowel perception, a bias that is often observed in infant discrimination data and also emerges in adult data in some contexts. Presently, these findings raise more questions than they answer. Nevertheless, in the context of basic research converging on a global conclusion that peripheral vowels have unique properties in speech perception, the perceptual implications of these asymmetries merit further investigation. Such efforts may well uncover some fundamental aspects of human vowel perception and its ontogeny. Until then, an awareness of these patterns should assist researchers in the design and interpretation of vowel perception experiments.

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