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Perception of Vowel Length by Japanese- and English-Learning Infants

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This study investigated vowel length discrimination in infants from 2 language backgrounds, Japanese and English, in which vowel length is either phonemic or nonphonemic. Experiment 1 revealed that English 18-month-olds discriminate short and long vowels although vowel length is not phonemically contrastive in English. Experiments 2 and 3 revealed that Japanese 18-month-olds also discriminate the pairs but in an asymmetric manner: They detected only the change from long to short vowel, but not the change in the opposite direction, although English infants in Experiment 1 detected the change in both directions. Experiment 4 tested Japanese 10-month-olds and revealed a symmetric pattern of discrimination similar to that of English 18-month-olds. Experiment 5 revealed that native adult Japanese speakers, unlike Japanese 18-month-old infants who are presumably still developing phonological perception, ultimately acquire a symmetrical discrimination pattern for the vowel contrasts. Taken together, our findings suggest that English 18-month-olds and Japanese 10-month-olds perceive vowel length using simple acoustic–phonetic cues, whereas Japanese 18-month-olds perceive it under the influence of the emerging native phonology, which leads to a transient asymmetric pattern in perception.

Keywords: vowel length, discrimination, cross-language speech perception, development of speech perception

The development of a phonetic system consisting of speech sounds specific to an infant's linguistic environment has been shown to involve perceptual learning processes and has been extensively documented for the second half of the 1st year of life. However, few studies have investigated the pattern of change beyond the end of the 1st year, after the infant has begun to establish a receptive lexicon. This article seeks to fill this gap by focusing on cross-language speech perception from the end of the 1st year to the middle of the 2nd year of life.

In the early months of life, infants discriminate both native and non-native phonetic differences, but by the end of the 1st year, infants—like adults—show better discrimination of native than of non-native distinctions. A classic study by Werker and Tees (1984) illustrates this perceptual change. English-learning infants 6–8 months old discriminated the Hindi dental /t̪a/ and retroflex /ta/ syllables, but no longer did so at 10–12 months old. Ten- to 12-month-old Hindi infants continued to discriminate this distinction.

This change in discrimination within the 1st year of life has been reported for English-learning infants for several different consonant contrasts, including synthesized versions of the Hindi retroflex–dental contrast (Werker & Lalonde, 1988); natural Nthalamkampx/Thompson Salish velar and uvular ejectives (Anderson, Morgan, & White, 2003; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Werker & Tees, 1984), and French and Spanish voicing distinctions (Burns, Werker, & McVie, 2003, and Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005, respectively). Similar declines in performance have been reported for Japanese-learning infants' discrimination of English /r/ and /l/ (Kuhl et al., 2006).

The decline in non-native perception is best described as a reorganization rather than a loss (see Werker, 1995). When tested in tasks with lower memory or decision loads, there is evidence of continuing, albeit less accessible, sensitivity to non-native contrasts by both adults (e.g.,Werker & Logan, 1985) and infants (Rivera-Gaxiola et al., 2005). Moreover, decline is not the only pattern of change seen. There is also improvement across the infancy period in the precision of discrimination of native contrasts (Kuhl et al., 2006; Tsao, Liu, & Kuhl, 2006) and realignment in the location of boundaries (Burns, Yoshida, Hill, & Werker, 2007). There are also reports in the literature of a temporary decline at 8 months old in bilingual infants in discrimination of a vowel con-

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trast of one of their two languages before a successful reemergence of discrimination again at 12 months (Bosch & Sebastián-Gallés, 2003; Sebastián-Gallés & Bosch, in press).

Attempts to understand the perceptual learning mechanisms that might account for the changes in speech perception in the 1st year of life have centered on similarity matching algorithms (e.g., Best & McRoberts, 2003; Kuhl, 2004). Empirical support for a similarity matching mechanism as underlying perceptual change has recently been provided by Maye, Werker, and Gerken (2002). Using an artificial language learning manipulation, they showed that infants as young as 6 months could track relative frequencies of differing sound tokens to modify their phonetic categories to reflect the properties of the speech they hear. Following 2 min of familiarization, infants who had been exposed to a bimodal distribution were better able to discriminate the endpoints of the continuum than were infants who had been exposed to a unimodal distribution. This distributional account has been posited to explain not only maintenance and improvement in performance across the 1st year of life, but also realignment (Burns et al., 2007) and the temporary decline in bilinguals (Bosch & Sebastián-Gallés, 2003; also see Sebastián-Gallés, 2006, for further discussion).

It is important to note that not all non-native contrasts become difficult to discriminate. The most striking example is certain non-English Zulu click contrasts, which, although not used in English, remain discriminable by English speakers across the life span (Best, McRoberts, & Sithole, 1988; also see Best & McRoberts, 2003). Best et al. (1988) suggested two reasons: (a) The Zulu click contrasts are distinguished by cues that are acoustically quite salient and (b) clicks fall outside of the English phonological space and hence may not be assimilated to English phonemic categories. The influence of acoustic salience on continuing discrimination of phonetic differences that are not part of the phonological system of a language is central to understanding developmental changes in speech discrimination.

Vowels are known to be perceived differently from consonants. Native vowels are perceived less categorically than are consonants by adults (e.g.,Scholuten & van Hessen, 1992), and it has been speculated that vowels might play a different role in language processing than consonants (Bonatti, Peña, Nespor, & Mehler, 2005). Nonetheless, there is also reorganization in the perception of vowel contrasts in infancy. Although some studies have revealed a decline in non-native perception occurring at the same age as that seen for consonants (e.g., Cheour et al., 1998), other studies have suggested that the decline may occur at an even earlier age for vowels. Kuhl, Williams, Lacerda, Stevens, and Lindblom (1992) reported evidence of distinctive prototype effects for vowels in English- and Swedish-learning infants at 6 months of age. Similarly, Polka and Werker (1994) found effects of native language experience on vowel perception between 4 and 6 months, with further change by 10 months. Monolingual Spanish infants also stop discriminating a Catalan-specific vowel contrast between 4 and 8 months of age (Bosch & Sebastián-Gallés, 2003).

To date, studies of vowel perception have focused on vowel quality contrasts, such as that in *bet* and *bat*. Distinctions in vowel quality result from different configurations of the vocal chamber that result in different spectral profiles. In languages such as Finnish and Japanese, not only vowel quality but also vowel duration is a determining feature of vowel identity. In these languages, vowels are distinguished as short and long by their quantitative duration, and this distinction is phonemic, that is, it signals contrastive meaning. In Japanese, for example, the words /kado/ and /ka:do/, which differ only in the length of the vowel, have different meanings (*corner* and *card,* respectively). There are five short vowels—[a], [i], [u], [e], and [o]—in Japanese, and each of them has a long vowel counterpart—[a:], [i:], [u:], [e:], and [o:]. Although it is often difficult for non-native speakers of Japanese to learn to use these contrasts phonemically, native Japanese speakers have a robust and stable ability to categorize vowels on the basis of length (Kato, Tajima, & Akahane-Yamada, 2001; Toda, 2003). Similarly, Japanese infants must ultimately acquire knowledge not only about vowel quality features but also about vowel length to signal phonemic (meaningful) contrasts. However, very few behavioral studies have been conducted to date to investigate vowel length perception and its development in Japanese infants.

Vowels in English are classified on the basis of their differences in vowel quality and are distinguished primarily by their spectral properties. However, length is a secondary cue that often accompanies the spectral differences in English vowels. Indeed, the vowels [i:], [ei], [ɑ:], [ɔ:], [oʊ], [u:], [ai], [aʊ], [ɔI], and [ju] (e.g., the vowels in *beet, bait, hot, bought*, *boat*, *boot*, *bite, bout, void*, and *beaut*[*y*]) differ from the vowels [I], [ɛ], [æ], [ʊ], and [ʌ] (*bit, bet, bat*, *put*, and *but*) not only in spectral properties, but often also in duration. This distinction in English is often described as tense versus lax (Ladefoged, 2000). One characteristic of tense vowels is that they tend to be longer in duration than lax vowels. Recall, though, that vowel duration alone is not contrastive in English. Indeed, the more consistent difference between tense and lax vowels is the difference in spectral cues. Thus, for example, if one were to pronounce the word *bet* with an elongated /ɛ/ that did not differ in quality, this word would still be perceived by an English speaker as *bet*. To become proficient speakers of their language, English-learning infants thus eventually have to ignore length differences, at least for the purposes of listening for word meaning, whereas Japanese infants have to continue to attend to them.

Research to date is not consistent, however, on whether English-learning infants do indeed stop discriminating vowel length differences. Some previous research has indicated that English infants continue to be sensitive to vowel length differences, at least during the 1st year of life. Eilers, Bull, Oller, and Lewis (1984) tested 5- to 11-month-old English infants on their discrimination of a vowel length change. Although vowel shortening was not tested, infants detected a change that involved elongation of the vowel. More recently, Dietrich, Swingley, and Werker (2004) explored the ability of 10- to 12-month-old English infants to discriminate a vowel pair that differed only in length (i.e., /tam/ vs. /ta:m/) using a habituation–switch discrimination design (Stager & Werker, 1998; Werker, Cohen, Lloyd, Stager, & Casasola, 1998). Their results demonstrated that discrimination of vowel length differences is present in English-learning infants at the end of the 1st year, despite the absence of this distinction in their language.

There are recent data that raise the possibility that English infants stop discriminating vowel length differences in the 2nd year of life. Dietrich, Swingley, and Werker (2007) investigated word learning using a vowel length contrast. They tested the ability of 18-month-old infants to establish a link between two novel objects and two novel words that differed only in vowel length. In this experiment, English-learning infants and Dutch-learning infants were compared to examine language-specific influences on the phonemic interpretation of vowel length.[1] Although, as mentioned above, infants from English language backgrounds discriminated the vowel lengths at 10 to 12 months of age (Dietrich et al., 2004), when infants were tested in a word-learning task at 18 months, only Dutch infants succeeded. The English infants did not.

Why would English infants of 18 months fail, in a word learning task, to use a vowel length distinction that they were clearly able to discriminate at 12 months? One possibility is that differing task requirements underlie the two patterns of performance in English infants. Indeed, this is the interpretation offered by Dietrich et al. (2004). According to this possibility, English infants retain access to the durational acoustic cues for purposes of phonetic discrimination, but they are unable to use these cues in word-learning tasks because the distinction is not part of their emerging phonology (see also Werker & Curtin, 2005). This interpretation would predict that English infants will continue to discriminate a vowel length distinction when tested in a discrimination task rather than a word-learning task, even at 18 months.

A second possibility is that although English infants continue to discriminate vowel length differences at 10–12 months, they no longer do so—even in a simple discrimination task—at 18 months. By 18 months of age, infants have begun to acquire a lexicon, and as such, factors other than distributional regularity and acoustic salience guide perception. Infants' comprehensive vocabulary size can reach nearly 200 words as measured on the MacArthur-Bates Communicative Development Inventory by 16 months of age (Fenson et al., 1993; Ogura & Watamaki, 2004). After a sizable enough receptive lexicon is in place, phonological categories may emerge and serve to guide not only word learning, but also speech perception such that even acoustically salient non-native contrasts are no longer discriminable.

In this article, we investigate the development of vowel length perception. We have focused on the discriminability of a vowel length contrast in infants from two language backgrounds, Japanese and English, in which vowel length is phonemic and nonphonemic, respectively. First, we examine whether English infants have difficulty discriminating vowel length at 18 months of age. If acoustic salience shapes their perceptual skills, they should continue to discriminate it. However, if they are using native phonological categories to guide their perception, they should fail to discriminate it. We subsequently explore vowel length discrimination and its development in Japanese infants. Ultimately, Japanese infants have to learn that vowel length cues phonemic contrasts. As such, it is not known whether they treat the distinction as acoustic–phonetic or instead treat it as phonemic, even when tested in a simple discrimination task. The comparison of English and Japanese infants at 18 months of age helps to untangle the relative roles of acoustic salience and phonemic status in simple discrimination.

Infants from both English and Japanese homes were tested on their discrimination of paired nonsense words that contained a short or a long vowel, in which the contrast between the words was solely the length of this vowel (i.e., /taku/ vs. /ta:ku/). We conducted four infant experiments using a habituation–switch discrimination paradigm just as in Dietrich et al.'s (2004) study with 10- to 12-month-old English infants. In the first three experiments, 18-month-old infants participated: Experiment 1 tested English infants with English stimuli, and Experiments 2 and 3 tested Japanese infants with English and Japanese stimuli, respectively. After discovering a cross-linguistic difference in discrimination at 18 months of age, we tested 10-month-old Japanese infants to explore the vowel length distinction at a younger age, likely before it is processed phonemically (Experiment 4). In addition to these infant experiments, we conducted Experiment 5 to examine vowel length discrimination in Japanese adults who process durational information of vowels phonemically using well-established perceptual categories.

Experiment 1

We conducted this experiment to explore the ability of 18-month-old English infants to discriminate a vowel length contrast. At this age, infants have had extensive experience with their native language system, which does not contrast vowel length (Fenson et al., 1993; Ogura & Watamaki, 2004). If, on one hand, English infants still detect a vowel length difference at 18 months, it would indicate that they maintain the sensitivity to vowel duration documented at early ages (Dietrich et al., 2004; Eilers et al., 1984) even after they have begun to establish and use a native language phonology in which vowel length is not contrastive. On the other hand, a failure to discriminate would indicate that English infants have attuned their perception to only those distinctions that are functionally contrastive in the native language.

Method

Participants. All participants were full-term, healthy, normally developing infants without auditory or visual impairment and were raised in a monolingual Canadian English environment. These infants were recruited through visits to new mothers at British Columbia Women's Hospital and also through voluntary response to public service announcements. All infants came from homes in which English was the dominant language (≥80%), but in approximately half of the homes, a small percentage of a second language was also reported (e.g., Mandarin, Cantonese, Filipino, Burmese, and Greek). Participants came from predominantly middle class (lower to upper middle class) neighborhoods and reflected the ethnic diversity of Vancouver, British Columbia, one of the most diverse cities in Canada. Sixteen 18-month-old infants (8 boys and 8 girls; mean age = 17 months, 24 days; age range = 17 months, 15 days, to 18 months, 10 days) made up the final sample. Four additional infants were tested but excluded for the following reasons: fussiness ($n = 2$) and failure to reach the habituation criterion ($n = 2$).

Stimuli. Stimuli were the nonsense words /taku/ and /ta:ku/ for which the contrast between the two words resided solely in the length of the vowel /a/. Stimuli were recorded with both English and Japanese pronunciation. Stimuli with an English pronunciation were used for Experiments 1 and 2, and stimuli with a Japanese pronunciation were used for Experiments 3 and 4.

The recording took place in a soundproof booth. The speaker was an 18-year-old English–Japanese bilingual woman. She was asked to use infant-directed speech for the recordings because it

[1] Dietrich et al. (2007) chose English and Dutch for cross-linguistic comparison because unlike English, in Dutch duration is an important cue to the phonemic distinction of the low vowels, although it is not the only cue for these contrasts.

has been shown that infant-directed speech facilitates infant discrimination of both native and non-native contrasts (Karzon, 1985; Panneton Cooper & Ostroff, 2003). Several exemplars of /taku/ were recorded using English pronunciation in a constant intensity. Because English does not have long vowels, /ta:ku/ was not recorded. The recording also included several exemplars of /taku/ (short vowel variant) and /ta:ku/ (long vowel variant), using a Japanese pronunciation.[2]

On the basis of previous analyses of words in Japanese infant-directed speech in a mother–child interaction corpus (Werker et al., 2007), we chose a ratio of 1:2 for short and long vowels for which the short vowel was 100 ms. We selected and manipulated five exemplars from each language such that five pairs of vowels were created in which the initial vowel was 100 or 200 ms in length. Figure 1 shows waveform spectrograms of the 100-ms exemplars for each language. The vowel duration manipulation was implemented by lengthening and compressing the vowel of these tokens using the pitch synchronous overlap add algorithm available in the waveform editor Praat (Boersma & Weenink, 2004). This change preserves pitch contour and vowel quality characteristics while resulting in natural-sounding syllables. Manipulated stimuli in both pronunciations were judged as natural-sounding tokens by native speakers of each language. Also, the stimuli in Japanese pronunciation were correctly identified by eight native adult Japanese speakers as words containing a short or a long vowel (averaged rate of correct identification = 94%).

Apparatus. The experiment was conducted in a sound-attenuated test booth in the Department of Psychology at the University of British Columbia. The infant sat on the parent's lap approximately 46 in. from a 27-in. Mitsubishi CS-27205 video monitor. To draw the infant's attention to the monitor, the booth was dimly lit.

The audio stimuli were delivered at 65dB ± 5dB over Bose 101 speakers located below the monitor. Black curtains were hung between the ceiling and floor except for an opening through which the video monitor could be seen to block the infant's view of the rest of the front of the room. Infants were recorded using a Panasonic AG 180 video camera. The lens of the video camera peeked out of a 2.5-in. hole in the black curtain located 10 in. below the monitor. The video camera was connected to a display and recording device for online and offline coding of the infant's response. As a masking control during testing, the parent wore Koss TD/65 headphones over which music was played from a Panasonic XBS portable stereo.

An experimenter in an adjacent room monitored the infant's eyegaze direction. The experiment was controlled by the Habit 2002 program (Cohen, Atkinson, & Chaput, 2000) run on a Power Mac G4. Using the program, the experimenter, who was unaware of trial status, controlled the presentation of visual and auditory stimuli and recorded the infant looking times to the display by pressing a key on the computer keyboard.

Procedure. Before the experiment, the procedure was explained to parents, after which they signed a consent form. The experiment used a habituation–switch discrimination design (Stager & Werker, 1998; Werker et al., 1998). At the beginning of each trial, a rotating blue flower animation was presented as an attention-getter to recall the infant's attention to the display. Once the infant oriented to the display, the trial began. During trials, the auditory stimuli were presented with a red and black checkerboard as the visual stimulus. Each trial was 14 s long, and seven tokens were presented randomly (five recorded tokens with two tokens repeated) with an approximately 1-s interstimulus interval. Immediately following each trial, the attention-getter reappeared for the next trial.

The experiment consisted of a habituation and a test phase. Depending on which stimuli (either short or long vowel) infants heard during the habituation phase, they were divided into two groups. Half of the 16 participants ($n = 8$; 4 boys and 4 girls) were assigned to the short vowel condition, and the rest were assigned to the long vowel condition. The habituation criterion was set to 65% of the total looking time of the longest block of three trials. When the average looking time across a three-trial block decreased to the criterion, the habituation phase ended. If the 65% criterion was not reached by the end of 27 habituation trials, the habituation phase was also ended. We excluded infants who habituated in fewer than 9 trials or who failed to habituate within 27 trials from analysis.

Following the habituation phase, a test phase consisting of two trials began. One test trial was a "same" trial in which the stimuli presented during the habituation phase were presented again. During the other trial, the "switch" trial, stimuli with vowel length differing from that of the habituation phase were presented. We expected that if infants detected the stimulus change in a switch trial, they would attend longer during this trial than during a same trial. The presentation order of the test trials (same–switch or switch–same) was counterbalanced between infants.

After the experiment, a trained coder who was unaware of trial type judged infants' looking times on the basis of frame-by-frame observation using the digitized video record (frame rate = 1/30 s). Looking times obtained from this offline coding were used in the analyses.

Results and Discussion

We submitted mean looking times to a two-way mixed analysis of variance (ANOVA; habituation condition [short vs. long] × test trials [same vs. switch]). We found a main effect for test trials, with infants looking longer to the switch trial than to the same trial, $F(1, 14) = 15.801$, $p = .003$, $\eta_p^2 = .530$ ($M_{switch} = 6.77$ s; $M_{same} = 4.07$ s). There was no main effect for habituation condition, $F(1, 14) = 0.747$, $p = .402$, $\eta_p^2 = .051$, and no interaction, $F(1, 14) = 0.980$, $p = .339$, $\eta_p^2 = .065$. The lack of interaction between habituation condition and test trial indicated a symmetric discrimination pattern such that the infants detected both vowel elongation and shortening to a similar degree. Figure 2 shows the mean looking time of the infants for the same and switch trials in the test phase for each habituation condition.

The result of the ANOVA was further supported by a nonparametric analysis. A Wilcoxon signed-rank test revealed that infants looked longer at the switch trial than at the same trial in the short vowel condition (7 out of 8 infants looked longer at the switch trial; $Z = 2.380$, $p = .009$, one-tailed, $\eta^2 = .723$) and in the long

[2] Japanese and English pronunciations differed primarily in the articulation of the /t/ and the quality of the /u/. The former is slightly more dental and has a shorter voice onset time in Japanese than in English; the latter is closer to an unrounded monophthong, /ɯ/, in Japanese.

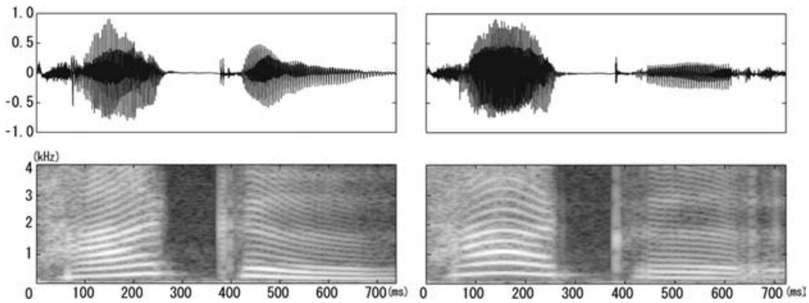

Figure 1. Waveforms and spectrograms of English (left) and Japanese (right) 100-ms vowel length exemplars.

vowel condition (6 out of 8 infants looked longer at the switch trial; $Z = 2.100$, $p = .018$, one-tailed, $\eta^2 = .563$).

This finding suggests that English infants do not lose sensitivity to the vowel length distinction even after they have had experience with a native language in which vowel length is not contrastive. Rather, the inability of English infants to link a word with an object in a word-learning task (Dietrich et al., 2007) can be attributed to their failure to use the vowel length cue to link novel words to novel objects, presumably because of the emergence by 18 months of more interpretative phonological categories, rather than simply acoustic–phonetic categories.

The discriminability of vowel length by English infants is apparently based on the perceptual saliency of the acoustic difference and seems to be beyond the influence of the native phonology. In Experiment 2, we explored the detection of vowel length change in Japanese infants whose native phonology requires phonemic processing of vowel length.

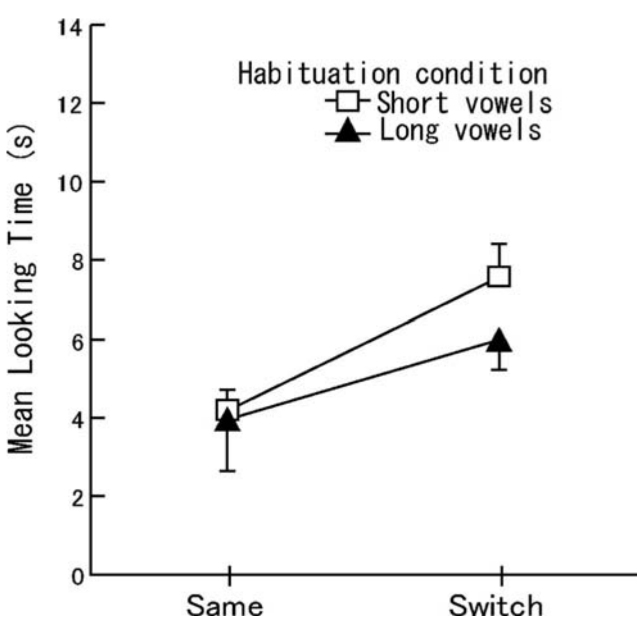

Figure 2. Mean looking times for the same and the switch trials of English 18-month-old infants in Experiment 1. Dishabituation for the switch trial was observed for both groups of infants, those who were habituated to the short vowel stimuli (squares) and those habituated to the long vowel stimuli (triangles). Vertical lines depict standard errors of the means.

Experiment 2

We conducted Experiment 2 to examine the discrimination of vowel length by 18-month-old Japanese-learning infants. If the fact that vowel length is phonemic affects infants' perception of vowel length, Japanese infants may show a different discrimination pattern of vowel length than that of English infants.

Method

Participants. Infants for this experiment and Experiments 3 and 4 were all full-term, healthy, normally developing infants without auditory or visual impairment; were raised in a monolingual Japanese environment by Japanese parents; and were recruited from middle-class neighborhoods. These infants were recruited by a human resources company through voluntary response to advertisements in a local town magazine. Sixteen 18-month-old infants (8 boys and 8 girls) remained as a final sample with a mean age of 18 months, 0 days (age range = 17 months, 17 days, to 18 months, 13 days). An additional 7 infants were tested but excluded from the analyses because of fussiness ($n = 1$) and failure to reach the habituation criterion ($n = 6$).

Stimuli, apparatus, and procedure. The experiment was conducted in a soundproof test booth in NTT Communication Science Laboratories (Kyoto, Japan). The overall apparatus was identical to Experiment 1, but the speaker was placed above the monitor and the peek hole for the video camera lens was located 10 in. below the monitor. We used a 19-in. Mitsubishi RDT-191S PC monitor and a Roland MS-50 speaker for stimuli presentation, a Sony DCR-PS120 video camera for recording infants' responses, and Sennheiser HDA200 headphones and a Sony CDP-A39 compact disc player for the masking control for the parents.

The stimuli and procedure were exactly the same as those reported for Experiment 1. As in Experiment 1, half of the infants ($n = 8$, 4 boys and 4 girls) were assigned to the short vowel condition, and the remaining half were assigned to the long vowel condition.

Results and Discussion

Mean looking times were submitted to a two-way mixed ANOVA (habituation condition [short vs. long] × test trials [same vs. switch]). There was no main effect for test trials or habituation; however, we found an interaction between the factors, $F(1, 14) = 5.120$, $p = .040$, $\eta_p^2 = .268$. A follow-up analysis of the interaction indicated a simple main effect of test trials in the long vowel condition, $F(1, 14) = 3.597$, $p = .031$, $\eta_p^2 = .291$ (M_{switch} = 9.57 s; M_{same} = 5.98 s), but not in the short vowel condition, $F(1, 14) = 1.204$, $p = .436$, $\eta_p^2 = .044$ (M_{switch} = 5.29 s; M_{same} = 6.49 s). This result indicates that infants who were habituated to the long vowel stimuli looked longer in switch trials than in same trials, whereas infants who were habituated to the short vowel stimuli looked equally long in both trials. Thus, we found an asymmetric discrimination pattern in Japanese infants for the detection of vowel length change; that is, the change from long to short vowel was detectable, but the opposite change seemed to be undetectable. Figure 3 shows the mean looking time of the infants in the test trials for each habituation condition.

We did not expect that the Japanese infants would fail to discriminate the short-to-long change that English infants easily discriminated. Because vowel length is phonemically contrastive in Japanese, we expected that Japanese infants' discrimination would be at least as reliable as that of English infants. However, a nonparametric Wilcoxon signed-rank test further supported the asymmetry. Infants in the long vowel condition looked longer at the switch trial than at the same trial (6 out of 8 infants looked longer at the switch trial; $Z = 2.432$, $p = .008$, one-tailed, $\eta^2 = .740$), whereas this was not the case for infants in the short vowel condition (4 out of 8 infants looked longer at the switch trial; $Z = 0.078$, $p = .470$, one-tailed, $\eta^2 = .001$).

Experiments 1 and 2 revealed that both English and Japanese infants discriminated vowel length. However, we observed different discrimination patterns for the two language groups: English infants discriminated both short-to-long and long-to-short vowel changes, whereas Japanese infants discriminated only the long-to-short vowel change. Given the fact that vowel length is a phonemic contrast in Japanese, discrepancies in the discrimination pattern could indicate that a native language phonemic system can affect vowel length discrimination.

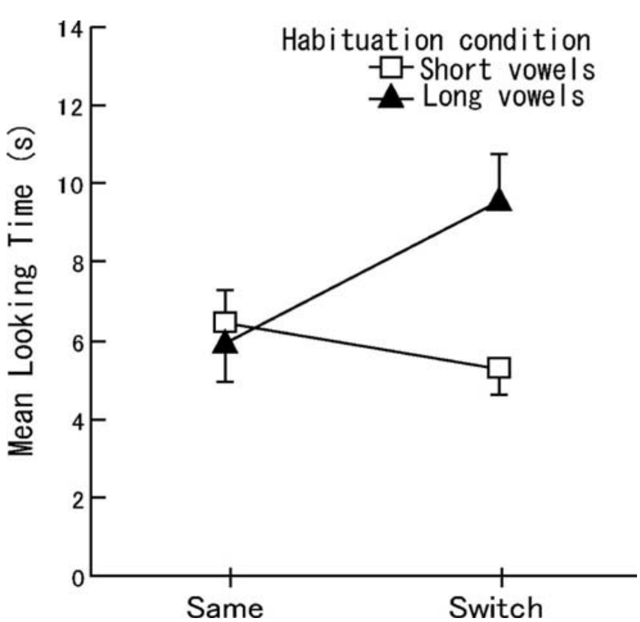

Figure 3. Mean looking times for the same and switch trials of Japanese 18-month-old infants in Experiment 2. Dishabituation for the switch trial was observed only for infants who were habituated to the long vowel stimuli (triangles). Vertical lines depict standard errors of the means.

An alternative explanation is that listening to foreign-pronounced stimuli might have influenced the performance of the Japanese infants and thus induced asymmetrical perception. In both Experiments 1 and 2, we used stimuli recorded in an English pronunciation to ensure that identical stimuli were used with both Japanese and English infants. Because Japanese is significantly different from English in many acoustic aspects, there exists a possibility that the English-pronounced words interfered with the ability of Japanese infants to discriminate the stimuli. Therefore, in Experiment 3, we tested 18-month-old Japanese infants using Japanese-pronounced stimuli to examine the reliability of the asymmetric discrimination pattern observed for English-pronounced stimuli.

Experiment 3

In this experiment, we used stimuli with a Japanese pronunciation to verify whether Japanese infants would still show an asymmetric pattern in vowel length discrimination when listening to more native-like stimuli.

Method

Participants. Twenty-four 18-month-old Japanese infants (12 boys and 12 girls) remained as a final sample, with a mean age of 18 months, 3 days (age range = 17 months, 19 days, to 18 months, 16 days). An additional 23 infants were tested but excluded from the analyses because of fussiness ($n = 8$) and failure to reach the habituation criterion ($n = 15$).

Stimuli. The paired disyllabic nonsense words /taku/ and /ta:ku/, recorded in Japanese pronunciation, were used as stimuli (see Experiment 1's *Stimuli* section for details).

Apparatus and procedure. The apparatus and procedure were identical to those reported in Experiment 2. As in previous experiments, half of the infants ($n = 12$, 6 boys and 6 girls) were assigned to the short vowel condition, and the remaining half were assigned to the long vowel condition.

Results and Discussion

We submitted mean looking times to a two-way mixed ANOVA (habituation condition [short vs. long] × test trials [same vs. switch]). There was no main effect for test trials or for habituation. However, we found a marginal interaction between the factors, $F(1, 22) = 3.366$, $p = .080$, $\eta_p^2 = .133$. A follow-up analysis of the interaction confirmed a simple main effect of test trial in the long vowel condition, $F(1, 22) = 6.081$, $p = .022$, $\eta_p^2 = .213$ (M_{switch} = 11.40 s; M_{same} = 9.13 s), but not in the short vowel condition, $F(1, 22) = 0.170$, $p = .899$, $\eta_p^2 = .001$ (M_{switch} = 7.71 s; M_{same} = 7.83 s). The results indicated that only infants habituated with the long vowel stimuli looked longer in the switch trials than in the same trials. As in Experiment 2, a Wilcoxon signed-rank test confirmed that infants in the long vowel condition looked longer at the switch trial than at the same trial (11 out of 12 infants looked longer at the switch trial; $Z = 2.432$, $p = .008$, one-tailed, $\eta^2 = .740$), whereas infants in the short vowel condition looked equally long at the same and switch trials (5 out of 12 infants looked longer at switch trials; $Z = 0.078$, $p = .470$, one-tailed, $\eta^2 = .001$). Therefore, the asymmetric discrimination observed in Experiment 2 was replicated using Japanese-pronounced stimuli. Figure 4 shows the mean looking time of the infants for the test trials in each habituation condition.

The results of the first three experiments revealed language-specific discrimination patterns at 18 months of age, namely asymmetry in Japanese infants and symmetry in English infants. We suggest that these different discrimination patterns in Japanese and English infants are the result of language-specific listening experience beginning to interact with an emerging, more interpretive phonological system. As noted earlier, vowel length is phonemic only for Japanese learners. We have argued that because length is not contrastive in English, English infants are continuing to perceive the stimuli in a nonphonemic manner and to focus on salient acoustic differences, which leads to a symmetric pattern of discrimination.

If this premise is accurate, younger Japanese infants whose perception has yet to be biased by the native phonology should discriminate long and short vowels on the basis of the acoustic salience of vowel length differences. To confirm this possibility, we carried out a subsequent experiment to test discrimination of vowel length in 10-month-old Japanese infants.

Experiment 4

In this experiment, we tested younger Japanese infants on their detection of vowel length change. In a previous study, Dietrich et al. (2004) found that 10- to 12-month-old English infants were able to detect the long-to-short vowel change, that is, the direction the 18-month-old Japanese infants failed to detect. To compare Japanese infants to English infants of a similar age, we chose 10-month-old Japanese infants for this experiment.

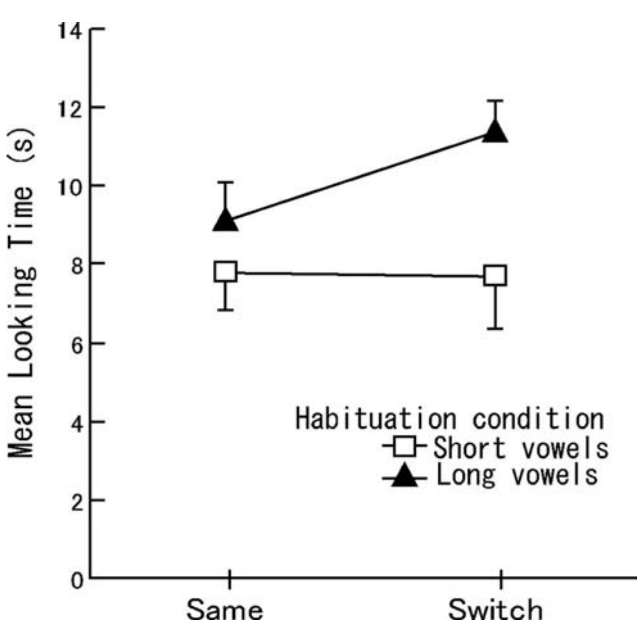

Figure 4. Mean looking times for the same and switch trials of Japanese 18-month-old infants in Experiment 3. Unlike in Experiment 2, the infants listened to the stimuli with a Japanese pronunciation. Dishabituation for the switch trial was observed only for infants who were habituated to the long vowel stimuli (triangles). Vertical lines depict standard errors of the means.

Method

Participants. Sixteen 10-month-old Japanese infants (8 boys and 8 girls) remained as a final sample with a mean age of 9 months, 28 days (age range = 9 months, 10 days, to 10 months, 15 days). An additional 9 infants were tested but excluded from the analysis because of fussiness ($n = 5$) and failure to reach the habituation criterion ($n = 4$).

Stimuli, apparatus, and procedure. The stimuli, apparatus, and procedure were identical to those reported in Experiment 3. As in previous experiments, half of the infants ($n = 8$; 4 boys and 4 girls) were assigned to the short vowel condition, and the remaining half were assigned to the long vowel condition.

Results and Discussion

We submitted mean looking times to a two-way mixed ANOVA (habituation condition [short vs. long] × test trials [same vs. switch]). A main effect for test trials was found, with infants looking longer at the switch trial than at the same trial, $F(1, 14) = 4.967$, $p = .043$, $\eta_p^2 = .262$ ($M_{switch} = 7.07$ s; $M_{same} = 4.87$ s). There was no main effect for habituation condition, $F(1, 14) = 0.783$, $p = .391$, $\eta_p^2 = .053$, and no interaction $F(1, 14) = 0.161$, $p = .694$, $\eta_p^2 = .011$. This result reveals that Japanese infants can detect the vowel length change at 10 months of age. Furthermore, the lack of interaction between habituation condition and test trial indicates that infants discriminated the change from long to short vowel and the change from short to long vowel as did English infants at 10 to 12 months (Dietrich et al., 2004) and at 18 months (Experiment 1). A Wilcoxon signed rank-sum test also supported the findings. Infants in the short vowel condition looked significantly longer at the switch trial than at the same trial (6 out of 8 infants looked longer at the switch trial; $Z = 1.960$, $p = .025$, one-tailed, $\eta^2 = .490$), and the infants in the long vowel condition looked marginally longer at the switch trial than at the same trial (4 out of 7 infants looked longer at the switch trial, and 1 infant had equal looking times at the same and the switch trials; $Z = 1.352$, $p = .088$, one-tailed, $\eta^2 = .230$). Figure 5 shows the mean looking time of the infants for the test trials in each habituation condition.

Experiment 5

Ten-month-old Japanese infants in Experiment 4 showed a symmetric discrimination pattern, whereas 18-month-old Japanese infants in Experiments 2 and 3 showed an asymmetric pattern of discrimination. This suggests that the asymmetrical perception of vowel length in Japanese infants emerges between 10 and 18 months of age. Does this asymmetric pattern persist into adulthood or is it a temporary pattern that is seen only at the beginning stages of the establishment of the native phonology? We conducted Experiment 5 to address this question. We tested vowel length discrimination in native adult Japanese speakers who, presumably,

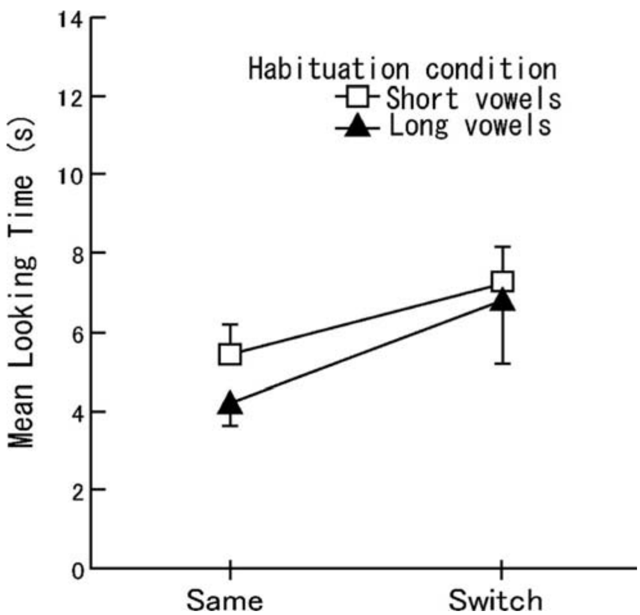

Figure 5. Mean looking times for the same and switch trials of Japanese 10-month-old infants in Experiment 4. Dishabituation for the switch trial was observed for both groups of infants, those who were habituated to the short vowel stimuli (squares) and those habituated to the long vowel stimuli (triangles). Vertical lines depict standard errors of the means.

have well-established phonemic categories for short and long vowels.

Method

Participants. Twenty native adult monolingual Japanese speakers (10 men and 10 women; M_{age} = 25.7 years, SD = 3.76) who had no health problems (including auditory or visual impairments) participated in the experiment. The participants were recruited by a human resources company.

Stimuli. A clear token was chosen from among the five exemplars of /taku/ in Japanese pronunciation that had been used as the stimuli for Experiment 3 and 4. In preparation for Experiment 5, we first tested native Japanese speakers to obtain an estimate of the short–long vowel category boundary. For this purpose, we generated a 21-step continuum by lengthening and compressing the first vowel of the selected token (as in the stimuli preparation for the infant experiments) so that it varied from 50 to 250 ms in 10-ms steps. Four native adult Japanese speakers identified the stimuli as being /taku/ or /ta:ku/ by listening to each of the 21 stimuli five times in random order. As shown in Figure 6, the Japanese speakers divided the continuum into distinct phonemic categories. A logistic curve was fitted to the response rate so as to estimate the perceptual boundary, defined to be the point at which a 50% response rate is obtained on the logistic curve. The estimated boundary was located at 120.8 ms.

After estimating the perceptual boundary for short and long vowels, we re-created the stimulus continuum for the discrimination experiment. Manipulating the first vowel of the original token as above, we created a 16-step continuum encompassing tokens whose initial vowel varied from 50 to 120 ms in 10-ms steps and 140 to 280 ms in 20-ms steps. The results from a pilot discrimination task indicated that longer vowels require longer durational differences to be discriminable. Thus, the stimuli in the long vowel category (>140 ms) were separated by 20 ms rather than 10 ms.

Each stimulus was paired with a maximum of six stimuli and a minimum of three. To limit the number of pairings, each stimulus was paired with every second stimulus from the continuum. For example, the 120-ms stimulus was paired with the six stimuli that had 60-, 80-, 100-, 160-, 200-, and 240-ms vowel lengths. The 50-ms stimulus (the shortest endpoint stimulus) was paired with the three stimuli that had 70-, 90-, and 110-ms vowel lengths. This resulted in a total of 72 pairs. Note that the direction of vowel length change (shorter vowel first or longer vowel first) was counterbalanced within the 72 pairs. In addition, 16 identical pairs were also included, for a total of 88 pairs. The interstimulus interval was set at 1,500 ms to promote phonological rather than phonetic discrimination (Werker & Logan, 1985).

Apparatus and procedure. On each trial, 1 of the 88 pairs of stimuli was dichotically presented to participants through headphones connected to a personal computer at a comfortable presentation level. Participants were asked to judge whether the stimuli in the pair were the "same" or "different" by pressing response buttons displayed on a computer screen. The discrimination experiment consisted of 11 blocks. The presentation of the 88 pairs was randomized within each block, for a total of 968 pairs. The participants were given a 1- to 3-min break after every block.

Results and Discussion

The 1st block served as a training block. For the remaining 10 blocks, we analyzed the effect of direction of vowel length change on discrimination. We calculated individual and group d' values for each of the 72 stimulus pairs that differed in vowel length. The calculation was done on the basis of participants' mean hit rates (obtained from 72 different pairs) and false-alarm rates (obtained from 16 identical pairs) using the roving methods proposed by Macmillan and Creelman (1991, pp. 147–152). To avoid an infinite value of d', any hit rates of 1.0 or false alarm rates of 0 were

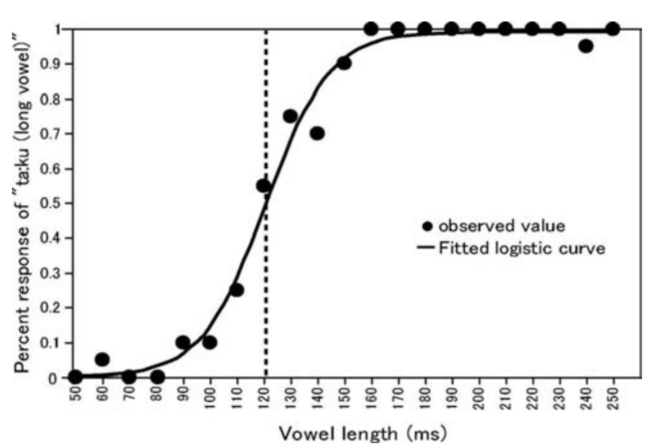

Figure 6. Percentage response of /ta:ku/ (long vowel) for each step of a 21-stimulus continuum of vowel length with a fitted logistic curve. The broken line represents the perceptual boundary between short and long vowel categories.

converted to $1 - 1/(2N)$ and to $1/(2N)$, respectively, where N is the number of hits or false alarms (see Macmillan & Creelman, 1991, p. 10).

First, we analyzed discrimination of the pair matching used in the previous infant experiments, namely 100 ms versus 200 ms. A paired t test revealed that there was no difference between the d' scores for either direction of vowel length change (100 ms to 200 ms vs. 200 ms to 100 ms), $t(19) = 0.77$, $p > 1$, $\eta^2 = .03$. This result revealed that adult native Japanese speakers discriminate long-to-short and short-to-long vowel changes equally robustly. Furthermore, the high discrimination scores ($M_{100\text{ ms–}200\text{ ms}} = 93.5$ %; $M_{200\text{ ms–}100\text{ ms}} = 95.0$ %) indicate that the 100-ms versus 200-ms difference is detected easily by native adult Japanese speakers.

Subsequently, we studied discrimination patterns in both between- and within-category pairs. The 72 pairs of stimuli, which differed in vowel length, were divided into three groups depending on the attribute types of the perceptual categories: (a) a short–short group (24 pairs) in which both members of the pair belonged to the short vowel category, (b) a long–long group (24 pairs) in which both members of the pair belonged to the long vowel category, and (c) a short–long group (24 pairs) in which one member of the pair belonged to the short vowel category and the other belonged to the long vowel category. We analyzed pairs in the short–short and long–long groups to verify within-category discrimination, whereas we analyzed those in the short–long group to verify between-category discrimination.

We submitted group d' scores for the 72 stimuli pairs to a two-way mixed ANOVA (category groups [short–short vs. long-long vs. short-long] × direction of vowel length change [short to long vs. long to short]). The main effect for category group was significant, $F(2, 33) = 14.493$, $p < .0001$, $\eta_p^2 = .468$. The main effect for direction was marginal, $F(1, 33) = 3.745$, $p = .062$, $\eta_p^2 = .102$. The interaction between factors, $F(2, 33) = 14.646$, $p < .0001$, $\eta_p^2 = .470$, was also significant. A follow-up analysis of the interaction indicated a simple main effect of direction in the short–short group, $F(1, 33) = 5.912$, $p = .021$, $\eta_p^2 = .152$, and the long–long group, $F(1, 33) = 26.751$, $p < .0001$, $\eta_p^2 = .448$, but not in the short–long group, $F(1, 33) = 0.374$, $p = .545$, $\eta_p^2 = .011$.

These results indicate that participants discriminated the long-to-short change of vowel length better than the short-to-long change for within-short-vowel-category discrimination, whereas they showed the opposite advantage for within-long-vowel-category discrimination. In other words, Japanese adults better discriminated the change from nonextreme toward extreme tokens of the category (shorter token in the short category and longer token in the long category) than the opposite change. However, we found no perceptual asymmetry for between-category discrimination.

General Discussion

In this study, we investigated the detection of vowel length differences in infants from two language backgrounds, Japanese and English, in which vowel length is either phonemic or nonphonemic. We conducted a series of four experiments (Experiment 1 to 4) using a habituation–switch discrimination paradigm. The results revealed that English 18-month-olds and Japanese 10-month-olds showed symmetric perception: They discriminated the sound change from a long to a short vowel as well as the change from a short to a long vowel. On the contrary, Japanese 18-month-olds showed asymmetric perception: They detected the sound change from a long to a short vowel, but they failed to detect the change in the opposite direction. An additional experiment (Experiment 5) revealed that unlike Japanese 18-month-old infants, native adult Japanese speakers discriminate the short and long vowel pairs from the infant experiments symmetrically.

We suggest that the success of the English 18-month-old infants in discriminating vowel length is made possible by two factors: (a) They remain sensitive to the acoustic–phonetic salience of the durational difference and (b) by this point in development, English infants are able to treat a difference in duration as "outside" their native phonological system. The fact that English 18-month-old infants succeeded in vowel length discrimination in this study but failed in a recently reported study (Dietrich et al., 2007) to use this distinction in word learning adds support to the interpretation that duration is not phonemic for English infants. When confronted with a task such as word learning, which demands use of phonological categories rather than just phonetic categories, English infants do not succeed. Hence, we can be confident that duration is not part of their phonemic system.

Vowel duration differences are acoustically salient. Vowel duration is a robust cue for adult listeners for differentiating non-native vowel contrasts, particularly if those non-native vowels are spectrally similar (Bennett, 1968; Bohn, 1995). Moreover, infants have been reported to show even higher levels of discrimination of durational differences in vowels than do adults when the vowels are spectrally similar (Polka & Bohn, 1996). On the basis of these findings, Bohn and Polka (2001) claimed that "vowel duration may be the more salient cue for inexperienced listeners when they confront spectrally similar vowels that differ in duration" (p.514; see also Bohn, 1995). The short and long vowels in our study are spectrally identical, and thus the difference in vowel duration might act as a strong acoustic cue for discrimination for the inexperienced 18-month-old English infants.

Although vowel length differences are not phonemic in English, they do serve paralinguistic functions. Vowel length, for example, indicates emphasis (e.g., "it's the caaar, not the bike, that is missing"), new versus old information, affect, and so forth. Experience treating vowel length as a paralinguistic cue could further divorce it, perceptually, from interpretive phonological processing, and hence facilitate unencumbered perceptual access to its salience acoustically.

When we compare the results of English 18-month-old infants to those of Japanese 10- and 18-month-old infants, we find interesting similarities and differences, respectively, in discrimination patterns. That is, Japanese 10-month-olds showed symmetric discrimination just as English 18-month-olds did, whereas Japanese 18-month-olds showed an asymmetric pattern of vowel length discrimination. These facts help us to understand the developmental trajectory for vowel length perception from a language-independent acoustic level to a language-specific phonemic level.

As explained earlier, we speculate that English infants discriminated vowel length using durational acoustic cues. The existing evidence indicates that Japanese 10-month-olds, who also showed a symmetric pattern of discrimination, likewise discriminate short and long vowels acoustically rather than phonemically. This evidence comes from two sources. First, Japanese infants comprehend, on average, only about five words at 10 months of age (Ogura & Watamaki, 2004). Given such a small vocabulary, we assume that Japanese infants at this age do not yet know a sufficient number of words to form the native phonemic category of vowel length (see Beckman & Edwards, 2000, and Werker & Curtin, 2005, for discussions of the emergence of phonemes). Second, brain imaging research has revealed no evidence for specialized linguistic processing of vowel length differences by Japanese infants until well after 10 months of age. Minagawa-Kawai, Mori, Naoi, and Kojima (2007) measured the cerebral hemodynamic responses of Japanese infants while they were exposed to Japanese short and long vowel contrasts. The results indicated that the left dominant activation of hemodynamics, which is the phoneme-specific response, did not appear until 13 months of age. At younger ages, activation was symmetric, indicating acoustic rather than linguistic processing. Given these facts, we speculate that symmetric discrimination as shown in Japanese 10-month-olds, like English 18-month-olds, reflects acoustic–phonetic (nonphonemic) perception of vowel length.

The symmetric discrimination for short and long vowels observed in Japanese 10-month-olds is replaced by an asymmetric pattern at around 18 months of age before reemerging as symmetric in adults. Although the pattern of discrimination is symmetric in both young infants and adults, we believe it is unlikely that the pattern of discrimination seen in adults rests entirely on the same underlying mechanism as that shown in infants. Because length is contrastive across the entire vowel system, Japanese adults must continuously use the distinction between long and short vowels to contrast meaning in words. Hence, although we cannot rule out the possibility that an acoustic basis contributes to their performance, there is every reason to presume that phonemic processing is even more important in driving the robust and symmetric adult discrimination of 100-ms versus 200-ms vowel length pairs in either direction of length change. In fact, U-shaped trajectories such as we report here between early infancy, early childhood, and later ages are often reported in speech processing development and are typically understood as revealing evidence of a reorganization (Pickens et al., 1994; Hayashi, Tamekawa, & Kiritani, 2001; Minagawa-Kawai et al., 2007; Stager & Werker, 1998; Werker, Hall, & Fais, 2004).

Still unanswered is why, among the groups we tested, only 18-month-old Japanese infants showed an asymmetry in vowel length discrimination. Why did this unique pattern emerge at that age? Asymmetric discrimination has been previously documented in young infants both for vowel quality (Kuhl et al., 1992; Polka & Bohn, 1996; Polka & Werker, 1994; Swoboda, Kass, Morse, & Leavitt, 1978; see also Polka & Bohn, 2003, for review) and for consonantal contrasts (Kuhl et al., 2006). There is reason to hypothesize that asymmetric discrimination of vowel quality may be a characteristic of the human perceptual system. Indeed, following a comprehensive review of relevant studies, Polka and Bohn (2003) proposed a peripherality hypothesis to account for the asymmetries in vowel quality perception in infants. According to this hypothesis, vowels from the extreme corners of the vowel space act as perceptually salient reference points: A change from a central vowel to a peripheral vowel is easier to detect than is a change in the opposite direction (see Harnad, 1987, and Warren, 1985, for discussion of factors influencing directionality effects).

The asymmetry in vowel quality and consonant discrimination previously reported is thought to be a language-universal phenomenon that is independent of influence from the native language phonology (Kuhl et al., 2006; Polka & Bohn, 1996; Polka & Werker, 1994), whereas the asymmetry in vowel length discrimination found here is specific to Japanese-learning, not English-learning, infants. In addition, the asymmetry in vowel quality perception is assumed either to be present at birth or to emerge quite early in development (Polka & Bohn, 2003; Swoboda et al., 1978), whereas the asymmetry for discrimination of vowel length that we found is acquired much later, following an initial symmetry.

These major differences suggest that the perceptual asymmetry we observed in vowel length perception is rooted in a different origin than the asymmetries previously reported in vowel quality perception. We interpret the asymmetric pattern obtained at 18 months of age to be a transient pattern that appears exclusively as Japanese infants are making the transition from treating vowel length as an acoustic–phonetic property to treating it as a phonological contrast. If we are correct and Japanese infants at this age are still developing the knowledge necessary to establish stable phonemic categories of vowel length, they are not able to treat 100-ms and 200-ms vowel length stimuli as constituting a canonical between-category pair in the same way that Japanese adults can. Recall that the Japanese adults showed an asymmetric pattern of discrimination both for within-short-vowel category pairings and for within-long-vowel category pairings. The direction of the asymmetry in each of these cases is consistent with a peripherality hypothesis, but more important, one that is apparent only for within-category discrimination. This fact raises the possibility that Japanese 18-month-olds treat the long–short pair somewhat analogous to a within-category contrast, but in this case a within-short-category distinction.

We would argue that Japanese 18-month-olds have had enough language experience that they no longer treat vowel length as strictly acoustic. Although their perception is not yet adultlike, they are starting to perceive vowel length phonemically. As a result, they show a different perceptual pattern than the 10-month-old infants. Their asymmetric perception indicates that the short vowel may serves as a reference point for vowel length comparison and facilitate the detection of changes toward it. The question here is why the developing phonemic system promotes the short vowel, not the long vowel, to be perceptually more salient in the vowel length dimension. Possible explanations can be found in specific characteristics of Japanese language input, namely distributional properties and frequency of occurrence.

Japanese short and long vowels have distinct differences in terms of their length distributions. According to the Japanese mothers' data provided in Werker et al. (2007), the distribution plots of short vowels in Japanese infant-directed speech have sharp, narrow peaks with small durational distributions, whereas those of long vowels are highly positively skewed with relatively flat peaks. Extensive variability in duration of long vowels is also seen in other analyses of speech produced by native Japanese speakers (Hirata, 2004). The greater consistency in the realization of short vowels may make them more stable reference points.

Frequency of occurrence can also contribute to the stability of reference points (Harnad, 1987). To examine potential differences in frequency, we analyzed a Japanese lexical database (Lexical

Properties of Japanese; Amano & Kondo, 1999–2000) and calculated the proportion of words with long vowel /a:/. Long /a:/ occurred in 2.66% of all the words containing either a long or a short vowel /a/; the other 97.34% contained short /a/. To obtain a more representative sample of the speech infants hear daily, we also analyzed a collection of Japanese infant-directed speech in a mother–child language database (Amano, Nakatani, & Kondo, 2006). The ratios of utterances containing long vowels to total mother's utterances are only 8.1% and 9.4% for each of the two mother–child dyads we analyzed. These results indicate that Japanese infants are exposed to a fairly small number of long vowels compared with short vowels.

If infants use distributional cues for tuning phonetic categories (Maye et al., 2002), concentrated exposure to short vowels with low distributional variety in duration may enhance the salience of short vowels relative to long vowels and hence confer a processing advantage for short vowels in the initial development of phonemic perception. The resulting perceptual advantage may allow short vowels to serve as initial reference points as 18-month-old Japanese infants make the transition to establishing more adultlike phonemic vowel length categories. Thus, just as distributional learning has been argued to account not only for maintenance and improvement in phonetic discrimination in the first year of life, but also for the temporary decline reported for bilingual infants (Bosch & Sebastián-Gallés, 2003), so too might distributional learning, in this case at the level of phonological categories, contribute to the temporary asymmetric pattern observed here for Japanese infants at 18 months.

If 18-month-old Japanese infants are developing phonemic categories for vowel length, and if the distributional characteristics of the input favor earlier development of the short vowel category as described previously, it would be plausible that long vowels are not initially categorized as long vowels, but rather are perceived as atypical, longer exemplars of short vowels. This is consistent with the pattern of peripherally oriented asymmetric perception that we saw in adult discrimination of within-category vowel length differences.

Compared with the language-specific perception for vowels and consonants that appears in the 1st year of life, one might think that 18 months of age is quite late to initiate reorganization of the perception of native vowel length contrasts. However, as we have argued above, it would appear that the change in vowel duration perception by Japanese infants is governed by different processes than are the changes seen in the 1st year of life in perception of vowel quality and consonant contrasts. Specifically, we have argued that at 18 months the change in perception of vowel duration results from a crossover from acoustic to phonological processing, and we have tried to spell out in detail how this might occur.

In summary, we investigated discrimination of the vowel length distinction by English and Japanese infants and by Japanese adults. Results revealed that although the vowel length distinction is not required for the purpose of phonemic categorization in their native language, English 18-month-old infants maintain the ability to discriminate vowel length differences using simple acoustic–phonetic cues. A cross-linguistic comparison of discrimination in English and Japanese 18-month-old infants revealed different patterns of discrimination for the two language groups: symmetry for English infants and asymmetry for Japanese infants. This strongly indicates a language-specific influence on vowel length discrimination. The symmetric pattern obtained for younger 10-month-old Japanese infants further confirms that following initial symmetric discrimination guided by simple acoustic cues, an asymmetry emerges as Japanese infants begin to treat vowel length phonemically. However, the across-category asymmetry eventually disappears when stable and fully productive phonemic categories for short and long vowels are established later in life.

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