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Cross-language word segmentation by 9-month-olds

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Dutch-learning and English-learning 9-month-olds were tested, using the Headturn Preference Procedure, for their ability to segment Dutch words with strong/weak stress patterns from fluent Dutch speech. This prosodic pattern is highly typical for words of both languages. The infants were familiarized with pairs of words and then tested on four passages, two that included the familiarized words and two that did not. Both the Dutch- and the English-learning infants gave evidence of segmenting the targets from the passages, to an equivalent degree. Thus, English-learning infants are able to extract words from fluent speech in a language that is phonetically different from English. We discuss the possibility that this cross-language segmentation ability is aided by the similarity of the typical rhythmic structure of Dutch and English words.

In their first year of life, children do not produce understandable language. But research in the past two to three decades has shown that the acquisition of language proceeds rapidly during that year. By the time children gratify their parents with the first comprehensible words, they have perceptually mastered the repertoire of speech sounds present in their native language. They have learned to distinguish phonetic contrasts (i.e., contrasts between speech sounds) that are important for telling the difference between words of the native language, and they can ignore contrasts that are not distinctive in the native language—even though shortly after birth they were indeed able to distinguish these nonnative contrasts (Best, Lafleur, & McRoberts, 1995; Werker & Tees, 1984). Children are enormously busy with language acquisition in their first year, and, by the end of that year, they have laid the foundation for vocabulary development and language production. Jusczyk (1997) describes the first year of speech perception in detail.

Experimental testing of infants younger than 1 presents considerable challenges to the investigator. There are now several different paradigms for establishing whether infants can make discriminations. In recent years, however, new tasks, called *auditory headturn preference tasks*, have led to dramatic advances in our knowledge of speech perception in the first year. In these tasks, which are particularly useful with infants 4 months or older, it is possible to establish via some response (e.g., how long an infant maintains a headturn) which of two speech inputs an infant prefers to listen to. A preference is still quite a simple mode of response, but it can be used to address a range of questions different from those that discrimination tasks can address. For instance, with preference tasks, it has been shown that infants listen longer to speech in the native language than to speech in another language (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993). Infants listen longer to interrupted speech when the interruptions do not break up intonational units than when they do (Hirsh-Pasek et al., 1987; Jusczyk et al., 1992). They listen longer to speech with high transition probabilities between speech sounds than to speech with low transition probabilities (Jusczyk, Luce, & Charles-Luce, 1994). They listen longer to words that are typical for their language than to words that are atypical (Jusczyk, Cutler, & Redanz, 1993). These experiments have shown not only that infants can tell the difference between, for instance, one language and another but that they actually prefer to listen to one than to the other.

The preference paradigm was adapted by Jusczyk and Aslin (1995) to address the important issue of segmentation of words from fluent speech. To build up a vocabulary, infants must extract new words from the speech contexts in which they occur. The vast majority of words addressed to infants occur in fluent speech, rather than as isolated words (van de Weijer, 1998; Woodward & Aslin, 1990). Woodward and Aslin (1990) discovered that even when parents were explicitly asked to teach their infants

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words, they still produced the target words in isolation only about 20% of the time. It is therefore vital that infants acquire the ability to extract individual words from longer utterances. Jusczyk and Aslin's (1995) approach to studying this issue involved augmenting the preference task with an initial familiarization phase. For instance, they familiarized infants with a pair of target words in isolation. Then, in the preference phase, they presented the infants with passages of short stories to listen to. Some passages contained multiple occurrences of one of the familiarized words. Jusczyk and Aslin found that infants preferred to listen to passages containing previously familiarized words rather than to passages containing multiple occurrences of words that had not been presented earlier. That is, the infants were able to detect the occurrences of the familiarized words within the fluent speech.

Not all infants preferred the familiarized words: 7.5-month-olds did, but 6-month-olds did not. Like many other preferences that show sensitivity to linguistically relevant factors, the ability to recognize familiar words in a continuous-speech context develops during the latter half of the first year of life.

Subsequent experiments showed that one of the important sources of information on which infants drew to perform this task was rhythmic word structure. Recall that English-learning infants prefer to listen to words that are typical for English (Jusczyk, Cutler, & Redanz, 1993). Such words are strong-initial (i.e., have stress on the first syllable): Bisyllabic words with strong/weak stress patterns form the most common English word type (Carlson, Elenius, Granström, & Hunnicutt, 1985). By a large majority, most English words in natural speech samples are, or begin with, strong syllables (Cutler & Carter, 1987). Research from other laboratories confirmed that infants are sensitive to this distributional pattern. Thus, Morgan (1996) found that 9-month-olds perceived novel bisyllables as cohesive only when they had a strong/weak stress pattern; Echols, Crowhurst, and Childers (1997) reported that English-learning 9-month-olds who were trained with three syllable sequences with weak/strong/weak stress patterns were significantly better at recognizing strong/weak sequences from these longer patterns than they were at recognizing weak/strong sequences.

Using Jusczyk and Aslin's (1995) familiarization preference paradigm, Jusczyk, Houston, and Newsome (1999; see also Newsome & Jusczyk, 1995) showed how stress rhythm was also important in segmentation of familiar words from speech. They familiarized 7.5-month-olds with pairs of strong-initial words (e.g., *hamlet, kingdom*) and tested them on four passages, two of which included these targets. The infants listened significantly longer to the passages with the familiarized targets, indicating that they detected the occurrence of these items in fluent speech. In other experiments, however, 7.5-month-olds familiarized with weak-initial words (e.g., *guitar, device*) did not listen longer to passages containing these items but did listen longer to passages containing the stressed syllables (*tar, vice*) of the familiarized words. Thus, the infants found it easier to detect strong-initial familiar portions of the passages.

Although the first year of life is noted for the development of sensitivity to the native language, this does not of course necessarily imply that all ability to deal with nonnative input is lost. It would indeed be remarkable if this were so, since, before puberty, children are notoriously good at learning second and further languages. We can distinguish here between the specialized processes for distinguishing native phonetic contrasts and more general abilities, such as the detection of a familiar sequence in a fluent-speech context. Certainly, phonetic discrimination for contrasts not manifested in the environmental language is lost by the end of the first year. But does the detection of word patterns in speech depend on this, such that word patterns can only be detected in native input? Or can the latter ability be exercised also on nonnative language? No study has as yet examined such an issue.

However, with the preference paradigm we can address these questions. Note that such tasks encourage only a single comparison at any one time: one language versus another, familiar versus unfamiliar words. We cannot, with listeners of this age, expect to address multiple questions in a single experiment. We already know that if infants are presented with native versus nonnative language, they prefer native. But if all that is offered is nonnative language, will infants be able to exercise a preference for speech containing familiarized words?

In the present study, we asked this question, using one of the languages used in the study in which American infants preferred to listen to English over a nonnative language (Jusczyk, Friederici, et al., 1993). Dutch differs from English in many phonetic features, and, by 9 months of age, infants are sensitive to these differences (Jusczyk, Friederici, et al., 1993). Thus, Dutch enables us to test whether a nonnative language, containing phonetic contrasts and transition probabilities that differ from those of the native language, will simply be rejected by infant listeners, such that they do not even try to look for familiar words in it, or whether familiar words can be found even in such nonideal input. We chose words for familiarization that conformed to the American infants' preferred strong-initial rhythmic structure. This was easy, given that Dutch resembles English in rhythmic structure (Rietveld & Koopmans-van Beinum, 1987), and most Dutch words begin with strong syllables (Schreuder & Baayen, 1994). The group of American English-learning infants, which were presented with this nonnative input, was compared with a group of Dutch-learning infants for whom the input would be native language.

METHOD

Subjects

Twenty-four 9-month-old Dutch infants (14 male, 10 female; mean age = 40 weeks 1 day; range = 39 weeks 2 days to 42 weeks

0 days) and thirty 9-month-old American infants (16 male, 14 female; mean age = 40 weeks 0 days; range = 37 weeks 4 days to 42 weeks 5 days) served as subjects. Forty additional infants (28 Dutch and 12 American) were tested but not included in the analysis for the following reasons: crying (11), looking times averaging less than 3 sec to the passages (10), not interested/restlessness (13), equipment failure (4), experimenter error (1), and parental interference (1). The better success rate of the American laboratory can at least in part be explained by more stringent criteria for time-of-day scheduling. All infants came from monolingual households.

Materials

Four words with a strong/weak stress pattern were used: *bokser* (boxer), *karper* (carp), *pendel* (hanging lamp), and *kusten* (coasts). These words were selected because the vowel qualities of the strong syllables differ, the weak syllable always contains a schwa, the onset consonant is always a stop consonant, and the Dutch infants were not likely to have had much earlier experience with these words. Although the Dutch passages contained phonetic segments that do not resemble an American English counterpart (non-English diphthongs, front rounded /y/, the velar fricative /x/), they did not include any sequences that violated the permissible orders of phonemes in American English. Importantly, none of these non-English phonetic segments occurred in the target words. Each target word occurred in every sentence, in varying sentential positions, in a six-sentence passage (see the Appendix).

Passages for each of the four target words were read in a lively voice by a phonetically trained adult female. She was instructed to read them as if she were talking to a small child. The recordings were made in a sound-attenuated booth with a Sennheiser ME40 microphone. The passages were recorded together with eight filler passages so that the speaker would not contrastively stress the target words. After reading the passages, the speaker repeated each target word (*bokser*, *karper*, *pendel*, *kusten*) with some variation, 15 times in a row. The word lists and the passages were digitized with the speech-editing system using a 16-kHz sampling frequency after low-pass filtering (cut-off frequency 8 kHz). Then, the duration of each passage, ranging from 16.25 to 19.61 sec, was set to a length of 20 sec by adjusting the silence between the sentences. The duration of the word lists, ranging from 17.6 to 21.7 sec, was set to a length of 21.5 sec by adjusting the silence between the 15 isolated words. In the Dutch laboratory, the word lists and passages were transferred to a PC with a program for executing real-time stimulus presentation tasks. In the American laboratory, the stimuli were transferred to a Power Macintosh, equipped with comparable software.

Design

Half of the infants in each language group were familiarized with the isolated words *bokser* and *karper*, and the other half were familiarized with *pendel* and *kusten*. Subsequently, they all heard four blocks of four passages (16 trials). The order of the passages within the blocks was randomized and counterbalanced across subjects.

Apparatus

Each infant was seated on a caregiver's lap in the center of a three-sided enclosure. A green light was mounted at eye level on the center panel. A red light was mounted on each of the side panels in front of a hidden loudspeaker. A video camera was situated behind the front panel (below the green light in the American laboratory and above the green light in the Dutch laboratory). In the Dutch laboratory, the camera was linked to a monitor in a separate room where the experimenter coded the infants' orientation times toward the lights. In the American laboratory, the experimenter observed from behind the front panel, and the session was recorded to check reliability in measuring the infants' orientations. During the course of the experiment, both the experimenter and the caregiver wore earplugs and listened to a masking tape over tight-fitting, closed headphones. The experimenter recorded the infant's headturns by pressing buttons on a response box that was connected to a computer. The computers recorded and stored the direction, number, and duration of the orientations.

Procedure

A modified version of the Headturn Preference Procedure was used in testing the infants (Kemler Nelson et al., 1995). Each trial began with the green light flashing to draw the infant's attention to the center. When the infant oriented to the center, the green light was extinguished and one of the red lights began to flash. When the infant oriented to the flashing light, the speech trial was initiated from the same side. Each trial continued until the infant looked away for 2 sec or until the maximum trial duration. The amount of time the infant oriented toward the light was recorded for each trial. The experiment had two phases. First, the infants were familiarized with two different target words on alternating trials, one target type per trial, until they accumulated at least 30 sec of orientation time to each word. The test phase consisted of four blocks of four trials. For each block, all four passages were presented in random order.

RESULTS

The mean orientation time to each of the passages was calculated for each infant across all four blocks. The mean orientation times were averaged for the two passages containing the familiarized words and for the two passages containing the unfamiliar words. Overall, 16 of the 24 Dutch infants and 20 of the 30 American infants had longer listening times for the passages containing the familiarized words. The average listening times for the infants from both language groups were longer to the passages with the familiarized words ($M = 7.30$ sec, $SD = 2.27$, for the Dutch infants; and $M = 7.29$ sec, $SD = 2.27$, for the American infants) than to the passages with the unfamiliar targets ($M = 6.31$ sec, $SD = 2.31$, for the Dutch infants; $M = 6.61$ sec, $SD = 2.96$, for the American infants). A 2 (native language: Dutch/English) $\times$ 2 (word type: familiar/unfamiliar) mixed design analysis of variance indicated that there was a significant main effect of passage type [$F(1,52) = 7.91, p < .01$]. The main effect of language environment was not significant [$F(1,52) < 1.00$]. Moreover, the language environment $\times$ passage type interaction was not significant [$F(1,52) < 1.00$], reflecting the fact that both language groups listened longer to the passages containing the familiarized targets and to an equal extent. The latter conclusion is also supported by analyses of the individual language groups, testing the prediction that infants would listen significantly longer to the passages containing the familiarized words. Paired t tests indicated that the listening time differences for the Dutch infants [$t(23) = 1.95$] and the American infants [$t(29) = 2.19$] were significant ($p < .05$, one-tailed). We also calculated effect sizes for each language group using the point biserial correlation measure described by Cohen (1988). Not only were effect sizes for each group large, according to Cohen's criteria (i.e., $r^2_{pb} > .14$), but they were virtually identical (r^2_{pb}s = .141 and .142, for the Dutch and American infants, respectively).[1] Of course, the absence of a significant statistical difference in the present study does not necessarily preclude the possibility that Dutch and American infants process the Dutch utterances differently. Still, the most interesting finding here is the fact that American infants are successful in segmenting words in an unfamiliar language.

DISCUSSION

The results of this study demonstrate that both Dutch-learning and English-learning 9-month-olds can segment strong-initial Dutch words from fluent Dutch speech. Our analysis failed to discern any difference in the two groups' success with this task: Infants of both language groups discovered the familiar words in the continuous utterances equally well. Previous research has demonstrated that English-learning infants can segment strong-initial words from English utterances (Jusczyk, Houston, Newsome, 1999; Newsome & Jusczyk, 1995). The present study shows that they can perform this task also with input in a nonnative language. A subsidiary result of our study (and see also Kuijpers, Coolen, Houston, & Cutler, 1998) is that Dutch 9-month-olds also show the familiarity preference for these words; like English-learning infants, they can recognize familiar words and extract them from continuous speech contexts.

Our results indicate that the ability to extract familiar words from fluent speech is not dependent on familiarity with the phonetic structure of the input. The phonetic features of Dutch differ in many ways from those of English, and 9-month-old infants can detect these differences; indeed, in previous studies, they have been shown to prefer the native language in a direct English–Dutch comparison (Jusczyk, Frederici, et al., 1993). Nonetheless, when Dutch was the only language offered, American infants preferred to listen to passages containing words with which they had been familiarized, in comparison with passages without familiar words.

The acquisition of a native language is an immense cognitive achievement. Perceptual skills are honed from the earliest exposure to language and are highly developed by the end of the first year of life, when linguistic production truly begins. By then, the infant is sensitive to the characteristic shape of words in the native language and to the phonetic patterns and phonotactic constraints of the language. Therefore, to a certain extent, 9-month-olds are already in command of a native language. They may not yet be native speakers, but they are well on the way to being native listeners.

One of the characteristics of native listening is sensitivity to rhythmic structure, as many studies with adult listeners have shown. As we described in the introduction, English and Dutch, though differing in many phonetic features, are similar in rhythmic structure. In both languages, there is experimental evidence that adult listeners exploit the stress-based rhythm to segment fluent speech into individual words. Thus, English-speaking adults identify word onsets with the occurrence of strong syllables when detecting words in nonsense strings (Cutler & Norris, 1988; McQueen, Norris, & Cutler, 1994) and when attempting to identify indistinct speech (Cutler & Butterfield, 1992). Both these results are also found with Dutch adults (Vroomen, van Zon, & de Gelder, 1996).

In other languages, with different rhythmic structures (e.g., the syllabic rhythm of French, or the moraic rhythm of Japanese), native listeners use different rhythmically based strategies in processing speech (Cutler, Mehler, Norris, & Segui, 1986; Cutler & Otake, 1994; Mehler, Dommergues, Frauenfelder, & Segui, 1981; Otake, Hatano, Cutler, & Mehler, 1993). Nonnative input with a different rhythmic structure from the native language does not of itself elicit the rhythmically based perceptual processing that native listeners use; so English listeners do not process nonnative input (e.g., in French or Japanese) in the way that native listeners of those languages do (Cutler et al., 1986; Otake et al., 1993), and neither do French and Japanese listeners process nonnative input in the way that it is processed by native listeners (Cutler et al., 1986; Cutler & Otake, 1994; Otake et al., 1993; Otake, Hatano, & Yoneyama, 1996).

Rhythmic structure is important for infants from the earliest period of language acquisition. Newborns and 2-month-olds from different language backgrounds do not discriminate between rhythmically similar languages such as English and Dutch (Christophe & Morton, 1998; Nazzi, Bertoncini, & Mehler, 1998), but they do discriminate rhythmically different languages such as French and English (Nazzi et al., 1998). French and American infants discriminate utterances in their native language from utterances in nonnative language even when the speech is low-pass filtered, leaving mainly intonational and rhythmic information (Mehler et al., 1988).

We suspect that the fact that English and Dutch are rhythmically similar may have played an important role in the present finding. We used strong-initial bisyllabic words, corresponding to the preferred rhythmic word pattern for both languages. American infants at this age do not succeed in detecting weak-initial English words in fluent speech (though older infants can do so; Jusczyk, Houston, & Newsome, 1999), so it is reasonable to suspect that infants at this age would also have difficulty detecting words with nonnative rhythmic structures, very unlike typical English word patterns. Indeed, some evidence exists that indicates that this is so: In a study by Newman and Jusczyk (reported in Jusczyk, 1998), English learners familiarized with target words in Mandarin Chinese displayed no evidence of segmenting these words from Mandarin Chinese passages. Moreover, the same pattern was observed for English-learning 7.5-month-olds who had received 10 h of experience listening to Mandarin Chinese prior to their participation in the study. Thus, for languages with different rhythmic structure than the native language, extended exposure to the language (and, presumably, to its rhythmic organization) may be necessary for word detection in fluent speech to occur. For languages within the same rhythmic structure as the native language, however, infants may simply be able to apply word segmentation strategies that they have developed for their own language.

To detect word boundaries in a continuous stream of speech, infants exploit not only rhythmic structure but also statistical regularities about co-occurrence relations between successive syllables (Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996) and cues to syllable structure such as those that distinguish *nitrates* from *night rates* (Jusczyk, Hohne, & Bauman, 1999). At an older age than 9 months, infants could perhaps use the phonetic features and transitional probabilities, which differ in English and Dutch, to help them find words (Myers et al., 1996). Further research will need to address how such factors affect the processing of nonnative input. In the meantime, the present findings demonstrate that language-learners can, in defiance of phonetic differences, detect familiar words within continuous utterances in another language, at least in one with the same rhythmic structure as their native language.

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NOTE

1. In preference studies with a single listener group, preference significance is typically calculated with two-tailed *t* tests. In the present case, the language group and preference effects are properly tested together in an analysis of variance, and, given the insignificant interaction between these effects, one-tailed *t* tests suffice to confirm the existence of the preference in each group independently. Note also that, in 61 previous experiments conducted in Peter Jusczyk's lab since 1994 and using this very same test procedure, 29 significant results and one marginal result were obtained. In every instance, the preference was for the passages containing the familiarized target. Hence, there is ample empirical support for using unidirectional *t* tests in the present study. Still, it is worth noting that the crucial case of the preference comparison for the American group would also have been significant by a two-tailed *t* test. The preference in the Dutch group was marginally (.06) significant on a two-tailed *t* test, due to the fact that one of the four passages failed to elicit a robust preference from the Dutch group. Preference across the other three passages was significant for the Dutch group on a two-tailed test.

APPENDIX
Passages Used in the Test Phase

Bokser Passage:
De bokser moet wel een erg sterke man zijn. Hij is de beste bokser van de hele wereld. Elke dag gaat hij trainen met een andere bokser. Die bokser is echter veel gespierder dan hij. Soms moet hij vechten tegen een nieuwe bokser. Dat is geen oude bokser maar een jonge.

Kusten Passage:
De kusten zijn hier bebouwd met hoge hotels. Aan de andere kusten zijn erg veel toeristen. Met de boot varen zij langs de nieuwe kusten. De visser kent alle oude kusten van dit land. Die kusten zijn nog niet door de gasten ontdekt. Morgen ga ik vissen bij de beste kusten.

Karper Passage:
De karper zwemt in de vijver bij de school. De jongen wil de nieuwe karper gaan vangen. Dan ziet de meester nog een andere karper. Hij moet nu de beste karper met rust laten. Die karper zal nog een hele tijd blijven leven. Nu gaan ze op de foto met de oude karper.

Pendel Passage:
Die pendel ligt op het bureau van mijn oom. Hij is dan ook erg trots op de beste pendel. Volgens hem is het al een heel oude pendel. Hij vindt deze nieuwe pendel iets minder apart. De pendel heeft hij in een dure zaak gekocht. Ik heb de andere pendel ook wel eens gebruikt.

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