Exploring possible effects of language-specific knowledge on infants' segmentation of an artificial language

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Introduction

English-learning infants begin segmenting words from fluent speech by 7.5 months (Jusczyk & Aslin, 1995). At this age, it appears that infants rely on two sources of information to segment speech: transitional probabilities between syllables (Saffran, Aslin, & Newport, 1996) and the predominance of word-initial stress in English (Jusczyk, Houston, & Newsome, 1999). However, Saffran et al. (1996a) demonstrated that infants can accurately parse a simple artificial language even when it contains no cues to word boundaries other than the statistical relationship between syllables. In the following study, we investigate the possibility that the infants in Saffran et al.'s study (1996a) were not parsing the entire trisyllabic words from the speech stream. In addition, we will explore the possibility that language-specific information affects the way infants segment an artificial language.

Saffran et al.'s (1996a) artificial language consisted of 4 tri-syllabic CVCVCV nonsense words ("pabiku", "tiboudo", "golatu", and "daropi") which were concatenated together into a two-minute stream of speech containing no cues to word boundaries other than the transitional probabilities between syllables. The transitional probabilities between syllables within words were 1.0, whereas transitional probabilities between syllables spanning word boundaries were 0.33. After familiarizing English-learning 8-month-olds to the two-minute speech stream, Saffran et al. used the headturn preference procedure to determine whether infant had parsed the speech stream in accordance with the statistical cues. Infants were tested on trisyllabic sequences of syllables corresponding to statistical words versus statistical partwords. All part-word test items contained the last syllable of one word plus the first two of another (i.e. part-word test item "tudaro" contained the last syllable of "golatu" plus the first two syllables of "daropi"). Infants listened reliably to the part-word test items, indicating their ability to segment the speech stream. These results were replicated by Johnson and Jusczyk (2001) using a natural speech stream which was closely matched to Saffran et al.'s on all relevant acoustic parameters such as rate and lack of prosody.

As mentioned above, all of the part-word test items used in the infant study by Saffran et al. (1996a) were creating by combining the last syllable of one word with the first two syllables of another word. In contrast, Saffran et al. (1996b) tested adults on two types of part-word test items. One type were created in the exact same manner as the test items used by Saffran et al. (1996a). The other half were formed by combining the last two syllables of a statistical word with the first syllable of another statistical word. Interestingly, adults performed at chance when it came to distinguishing this latter type of part-word (last two syllables of one word combined with first of another) from statistical words. Saffran et al. (1996b) suggested that this effect could be rooted in the way

transitional probabilities were calculated. In short, they invoked a non-linguistic or language-general explanation. However, another possibility may be that listeners were imposing some sort of language-specific structure on the artificial language. For example, we suggest a prosodic explanation for adults' difficulty with part-words containing the last two syllables of a statistical word. Namely, listeners may have imposed a structure characteristic of English on their speech input: the trochaic foot. In a trisyllabic English word with 3 unreduced syllables, stress would normally be placed on the penultimate syllable (Burzio, 1994). In a trochaic foot, the head of the foot is stressed, and an unstressed syllable to the right of the head will bind to the stressed syllable. This is known as a binary foot. Although Saffran et al's speech stream contained no speech cues like stress, it is not wholly implausible that listeners could impose a linguistic structure on the monotonous stream of syllables. For example, some subjects who were over-trained on the artificial language used in Saffran et al. (1996b) admitted that they felt like they could hear pauses separating the trisyllabic nonsense words. Thus, if listeners perceived the middle syllables as stressed, then the last syllable would bind to the middle syllable. This would form a trochaic foot, and the last two syllables might be perceived as more coherent than the first two. If this were so, this could explain why adults performed differently with different types of part-words. Test items containing the last syllable of one word and the first two of another would break an imposed foot boundary, and would therefore be more easily distinguished from statistical words.

Experiment 1

In Experiment 1, we familiarize English-learning 8-month-olds with the same language used by Johnson and Jusczyk (2001). During the test phase, infants are tested on their listening preferences to two types of stimuli: 1) the first two syllables of a statistical word, 2) the last two syllables of a statistical word. If infants rely on transitional probabilities alone to segment the speech stream, then no difference in the looking time to the two types of stimuli would be predicted. This result would present an interesting dilemma: Why do adults segment an artificial language differently than infants? On the other hand, if infants display a novelty preference for the test items corresponding to the first two syllables of a statistical word, then this suggests that infants may be doing more (or less) than simply segmenting the speech stream into trisyllabic words. If this latter result is obtained, additional experiments will be carried out to try to determine whether a non-linguistic or language-specific explanation underlies this effect.

<u>Methods</u>

Participants
        Twenty-four English-learning 8-month-olds from the Baltimore-Annapolis region were tested (14 Males and 10 females). The infants were approximately 8.0 months old (range 7.5-8.5), with a mean age of 243 days (Range: 225-258; SD=8.9). The data from an additional 3 infants were excluded for the following reasons: fussiness (2) and experimenter error (1). Participants were recruited to come to the lab via letters mailed by the Maryland State Health Department, advertisements in local parenting magazines,

and referrals from past participants. Parental consent was obtained for all participants. In appreciation for their participation, all infants were given a small toy or certificate and a $10 travel reimbursement.

Stimuli

This study used the same 2.5-minute speech stream used by Johnson and Jusczyk (2001). These stimuli were modeled after Saffran et al. (1996). Each speech stream contained four trisyllabic words that were randomly concatenated together with the stipulation that a given word never occurred twice in a row. The words were created out of 12 syllables that had been recorded in isolation (see Johnson & Jusczyk for details). Since no syllable was used in more than one word, the transitional probability between all syllables within words was equal to 1.0. The transitional probability between any two syllables spanning the boundary between two words, on the other hand, was always equal to .33. No pauses occurred between the words. Orthographically, one of the resulting speech stream would be as follows: pabikudaropitibudopabikugolatu….. Language A consisted of repetitions of the following four words: "pabiku", "tibudo", "golatu", and "daropi". Language B consisted of repetitions of the following four words: "tudaro", "pigola", "bikuti", and "budopa". Note that as in Saffran et al. (1996) and Johnson and Jusczyk (2001), the two languages (or speech streams) were constructed so that the part-words of each speech stream formed a statistical word in the other speech stream (if "daropi" and "golatu" were words in one language, then "pigola" would be a word in the other). This construction allowed us to test all infants on the same four test items: "biku", "budo", "gola", and "daro". Test items were concatenations of the individual syllables recorded for use in Johnson and Jusczyk (2001). They consisted of pair of syllables that occurred either at the beginning of a statistical word ("daro" from "daropi" if exposed to Language A, or "biku" from "bikuti" if exposed to Language B) or at the end of a statistical word ("biku" from "pabiku" if exposed to Language A, or "daro" from "tudaro" if exposed to Language B).

Design

All infants were randomly assigned to hear one of the two streams of speech (Language A or Language B). Twelve test trials were presented immediately after the familiarization phase. Half of the trials consisted of repetitions of two syllables corresponding to the onset of a statistical word ("daro" from "daropi"); the other half consisted of repetitions of two syllables corresponding to the offset of a statistical word ("biku" from "pabiku"). Note that the transitional probabilities between all the syllables in both types of test items are equal because both types of test items consist of syllable pairs taken from words (e.g. the transition between all syllable pairs is equal to 1.0). Therefore, the statistical structure of the languages alone should not cause infants to respond to these test items differently.

Procedure and Apparatus

Infants were tested using the same version of the Headturn Preference procedure used by Saffran et al. (1996). Infants sat in the center of a caregiver's lap. The caregiver was seated on a chair in the center of a three-sided booth made of white pegboard. A red light and a speaker were mounted at eye level on the center of each side panel, and a

green light was located at eye level on the center of the front panel. During the familiarization phase, the green light flashed at the start of each trial. Once the infant oriented towards the green light, one of the two speech streams played from the two side speakers continuously until the end of the soundfile was reached (approximately two minutes). Throughout the familiarization, in order to entertain the infants, all three lights in the testing booth were lit and extinguished in response to the infants' looking behavior (see Johnson & Jusczyk, 2001, for additional methodological details). The test phase immediately followed the familiarization phase. Each of the 12 test trials (three trials for each of the four test items) began with the blinking center light. Once the infant oriented toward the green light, the green light stopped blinking and one of the two side red lights began blinking. Once the infant oriented toward the blinking light, a test item was repeated with a 500 ms ISI until the infant looked away from the blinking light for more than 2 consecutive seconds or until 15 repetitions of the test item had occurred. Thus, the infant essentially controlled how long he or she heard the test items. There were three blocks of test trials. Each block contained four trials, one for each of the four words, presented in random order.

The experimenter recorded the direction and duration of infants' orientation via a botton box connected to a Macintosh computer. Computer software was responsible for the selection and randomization of the stimuli and for the termination of test trials. Both the caregiver and the experimenter wore tight-fitting headphones over which loud masking music was played (for a more thorough methodological discussion of the Headturn Preference Procedure, see Kemler Nelson et al., 1995). The dependent measure in this study was orientation time to different types of stimuli. As in Saffran et al. (1996) and Johnson and Jusczyk (2001), we predicted that infants would listen longer to novel-sounding stimuli.

All recordings were played at a comfortable listening level (approximately 72 dB SPL, according to a Quest (Model 215) sound meter. The audio output was generated from the digitized waveforms of the samples. A 16-bit D/A converter was used to recreate the audio signal. The output was fed through anti-aliasing filters and a Kenwood audio amplifier (KA 5700) to the two 7-inch Cambridge Soundworks loudspeakers mounted on the side walls of the testing booth.

Results and Discussion

Mean orientation times to the types of test items (first two syllable of a statistical word versus last two syllables of a statistical word) during the test phase were calculated for each infant. Eighteen out of 24 infants had longer orientation times for the first two syllables of a statistical word. Across all infants, the average orientation times were 6.82 seconds (SD = 2.08) for the first two syllables of a statistical word and 6.07 seconds (SD = 2.19) for the last two syllables of a statistical word. A 2 X 2 mixed design ANOVA with Condition (familiarized with Language A versus Language B) and test item (first two syllable of a statistical word versus last two syllables of a statistical word) revealed a significant effect of test item, $F(1, 22) = 4.99$, $p < .05$. There was no significant effect of group, $F(1, 22) = .3$, $p > .1$. In addition, there was no significant interaction between test item and group, $F(1, 22) = 2.07$, $p > .1$. Thus, it appears that English-learning 8-month-olds segment the last two syllables of a statistical word more readily than the first two syllables.

This finding is consistent with the hypothesis that infants impose language-specific stress patterns on an artificial language containing no cues to word boundaries other than the transitional probabilities between syllables. However, there are alternative explanations for this finding that do not invoke language-specific knowledge to account for infants' segmentation performance. For example, the ends of words might just be more salient to infants. Saffran et al. (1996b) discuss language-general reasons why the ends of words might be more salient to listeners. For example, they suggest that the "listener tends to maintain" the information about the end of a word because the end of the word "has anchored the computations required to discover a word boundary" (pp. 615). Additional support for this language-general explanation comes from adults' attention to the ends of units when segmenting a continuous stream of tones into recurring elements (Saffran, Johnson, Aslin, & Newport, 1999). However, other researchers have argued that language users can impose linguistic knowledge on non-linguistic input, such as tone streams (Kosumoto, Kiyomi, & Moreton, 1997).

Experiment 2

In Experiment 1, English-learning 8-month-olds segmented bisyllables occurring at the end of a statistical word more readily than they segmented bisyllables occuring at the beginning of a statistical word. One possible explanation for this finding is that infants are imposing stress on the second syllable of the trisyllabic words (a stress pattern characteristic of trisyllabic words in English). By doing so, infants may perceive the final two syllables of the word as more cohesive than the first two because the final two syllables form a trochaic foot. On the other hand, infants' behavior in Experiment 1 may have nothing to do with their knowledge of how English stress patterns. One way to test these possibilities is to use these same materials to test infants who do not know about English stress. Past research has shown that English-learning 6-month-olds have not yet learned about how stress patterns in English (Jusczyk, Cutler, & Redanz, 1993). Thus, if 6-month-olds were to show the same bias for recognizing the ends of words, then it is unlikely that the results obtained in Experiment 1 were due to 8-month-olds' knowledge of the prosodic structure of English. However, past studies have argued that 6-month-olds cannot segment words from fluent speech (Jusczyk & Aslin, 1995). Therefore, before testing 6-month-olds' recognition of the ends versus the beginnings of words, we decided to test 6-month-olds' ability to segment an artificial language. Even though there is no evidence that 6-month-olds can segment words from natural speech, it is possible that 6-month-olds can segment a simplified language containing only four words.

In Experiment 2, infants were tested using the same familiarization languages used in Experiment 1. However, instead of testing the 6-month-olds on the onsets and offsets of statistical words, we tested them on statistical words versus statistical part-words. In short, we attempted to replicate Experiment 1 of Johnson and Jusczyk (2001) with 6-month-olds rather than 8-month-olds. If 6-month-olds can segment the artificial language, then they should display a novelty preference (e.g. they should display longer orientation times to statistical part-words rather than statistical words).

Methods

Subjects

 Twenty-four English-learning 6-month-olds from the Baltimore-Annapolis region were tested (15 Males and 9 females). The infants were approximately 6.0 months old (range 5.5-6.5), with a mean age of 182 days (Range: 165-198; SD = 9.04). The data from 4 additional infants were excluded for the following reasons: fussiness (2) and experimenter error (2). Participants were recruited to come to the lab via letters mailed by the Maryland State Health Department, advertisements in local parenting magazines, and referrals from past participants. Parental consent was obtained for all participants. In appreciation for their participation, all infants were given a small toy or certificate and a $10 travel reimbursement.

Stimuli

 The same stimuli were used as in Experiment 1 in Johnson and Jusczyk (2001). These stimuli were modeled after those used in Saffran et al. (1996).

Design

 All infants were randomly assigned to hear one of the two streams of speech (Language A or Language B). Twelve test trials were presented immediately after the familiarization phase. Half of the trials consisted of repetitions of statistical part-words; the other half consisted of repetitions of statistical words. All infants were tested on the same four test items: "tibudo", "pabiku", "tudaro", and "pigola".

Procedure and Apparatus

 The same procedure and apparatus were used as in Experiment 1.

Results and Discussion

 Mean orientation times to the types of test items (statistical word versus statistical part-word) during the test phase were calculated for each infant. Nine out of 24 infants had longer orientation times for the novel part-words. Across all infants, the average orientation times were 7.44 seconds (SD = 2.85) for the novel part-words, and 8.37 seconds (SD = 2.33) for the familiar words. A 2 X 2 mixed design ANOVA with Condition (familiarized with Language A versus Language B) and test item (statistical word versus statistical part-word) revealed no significant effect of test item, $F(1, 22) = 2.04$, $p > .1$. There was a significant effect of group, $F(1, 22) = 10.1$, $p < .01$, however, there was no significant interaction between group and test item, $F(1, 22) = .34$, $p > .1$. These results suggest that in contrast to 8-month-olds, English-learning 6-month-olds cannot segment an artificial language based on statistics alone.

Experiment 3

 In Experiment 2, 6-month-olds failed to show any evidence of segmenting the artificial language. If we can find no evidence that 6-month-olds can use transitional

probabilities to segment an artificial language, then we cannot test whether 6-month-olds recognize the latter portion of words more readily than they recognize the initial portion. In short, we cannot see if the results of Experiment 1 are due to 8-month-olds' knowledge of how stress typically patterns in English. Therefore, in Experiment 3, we try to make the task a little easier for the 6-month-olds by testing them on statistical non-words rather than statistical part-words. In Experiment 2, statistical part-words were formed by taking the last syllable of one statistical word and combining it with the first two syllables of another statistical word (e.g. "pigola" formed by taking the combining the last syllable of "daropi" with the first two syllables of "golatu"). Thus, all test sequences actually occurred during the familiarization. In Experiment 3, non-words are formed by combining a sequence of syllable in an order that never occurred during the familiarization (e.g. "tilado" formed from combining the two syllables in "padoti" with the middle syllable of "golabu"). Adults seem to perform slightly better when they are tested on non-words as opposed to part-words (Saffran et al., 1996). Therefore, it is possible that 6-month-olds will show evidence of segmenting the artificial language when they are tested on non-words. If infants in Experiment 3 display a novelty preference for non-words, then we will have evidence that 6-month-olds have at least some ability to segment an artificial language by tracking transitional probabilities between syllables.

Methods

Subjects

Twenty-four English-learning 6-month-olds from the Baltimore-Annapolis region were tested (10 Males and 14 females). The infants were approximately 6.0 months old (range 5.5-6.5), with a mean age of 179 days (Range: 142-208); SD=16.5). The data from 2 additional infants were excluded due to fussiness. Participants were recruited to come to the lab via letters mailed by the Maryland State Health Department, advertisements in local parenting magazines, and referrals from past participants. Parental consent was obtained for all participants. In appreciation for their participation, all infants were given a small toy or certificate and a $10 travel reimbursement.

Stimuli

The twelve isolated CV syllables used in Johnson and Jusczyk (2001) were concatenated into two new 2.5-minute speech streams. Language A consisted of repetitions of the following four words: "tupiro", "golabu", "bidaku", and "padoti". Language B consisted of repetitions of the following four words: "dapiku", "tilado", "burobi", and "pagotu." Test items were concatenations of the individual syllables recorded for use in Johnson and Jusczyk (2001). Half of the test items consisted of 3-syllable sequences that corresponded to a statistical word; the other half were 3-syllable sequences that never occurred together during the familiarization.

Design

All infants were randomly assigned to hear one of the two streams of speech (Language A or Language B). Twelve test trials were presented immediately after the familiarization phase. Half of the trials consisted of repetitions of statistical non-words; the other half consisted of repetitions of statistical words. The statistical words of

Language A formed non-words in Language B, and vice versa. Therefore, all infants were tested on the same four test items: "tupiro", "golabu", "dapiku", and "tilado".

Procedure, Apparatus
     The same procedure and apparatus were used as in Experiment 1.

Results and Discussion

     Mean orientation times to the types of test items (statistical word versus statistical non-word) during the test phase were calculated for each infant. Thirteen out of 24 infants had longer orientation times for the novel non-word test items. Across all infants, the average orientation times were 8.49 seconds (SD = 1.6) for the novel non-words, and 8.44 seconds (SD = 2.13) for the statistical words. A 2 X 2 mixed design ANOVA with Condition (familiarized with Language A versus Language B) and test item (statistical word versus statistical non-word) revealed no significant effect of test item (F < 1). There was a marginal effect of group, $F(1, 22) = 4.3$, $p < .1$. Importantly, however, there was no significant interaction between test item and group (F < 1). Once again, as in Experiment 2, 6-month-olds failed to exhibit any ability to use statistical cues to segment the artificial language.

Experiment 4

     Experiments 2 and 3 failed to provide any evidence that 6-month-olds can use statistical information to segment an artificial language. In Experiment 4, we attempt to simplify the task for the 6-month-olds even further by adding coarticulatory cues that coincide with the statistical cues to word boundaries. If adding coarticulatory cues makes the artificial language easier to segment, then infants should display a novelty preference for statistical part-words.

Methods

Subjects
     Twenty-four English-learning 6-month-olds from the Baltimore-Annapolis region were tested (12 Males and 12 females). The infants were approximately 6.0 months old (range 5.5-6.5), with a mean age of 186 days (Range: 174-202; SD = 7.7). The data from 4 additional infants were excluded for fussiness. Participants were recruited to come to the lab via letters mailed by the Maryland State Health Department, advertisements in local parenting magazines, and referrals from past participants. Parental consent was obtained for all participants. In appreciation for their participation, all infants were given a small toy or certificate and a $10 travel reimbursement.

Stimuli
     The same stimuli were used as in Experiment 4 in Johnson and Jusczyk (2001). Language A consisted of repetitions of the following four words: "pabiku", "tibudo", "golatu", and "daropi". In Language A, "pabiku" and "tibudo" were coarticulated to facilitate segmentation. Language B consisted of repetitions of the following four words:

"tudaro", "pigola", "bikuti", and "budopa". In Language B, "tudaro" and "pigola" were coarticulated to facilitate segmentation. Test items were uncoarticulated concatenations of the individual syllables recorded for use in Johnson and Jusczyk (2001). Half of the test items consisted of 3-syllable sequences that corresponded to a statistical word; the other half were 3-syllable sequences corresponding to statistical part-words.

Design
   All infants were randomly assigned to hear one of the two streams of speech (Language A or Language B). Twelve test trials were presented immediately after the familiarization phase. Half of the trials consisted of repetitions of statistical part-words; the other half consisted of repetitions of statistical words. The statistical words of Language A formed part-words in Language B, and vice versa. Therefore, all infants were tested on the same four test items used in Experiment 2: "pabiku", "tibudo", "tudaro", and "pigola".

Procedure and Apparatus
   The same procedure and apparatus were used as in Experiment 1.

Results and Discussion
   Mean orientation times to the types of test items (word versus part-word) during the test phase were calculated for each infant. Eleven out of 24 infants had longer orientation times for the novel part-words. Across all infants, the average orientation times were 7.87 seconds (SD = 1.8) for the part-words and 7.9 (SD = 2.1) for the words. A 2 X 2 mixed design ANOVA with Condition (familiarized with Language A versus Language B) and test item (word versus part-word) revealed no significant main effect of test item (F < 1) or group (F < 1). In addition, there was no significant interaction between test item and group, F(1, 22) = 1.65, p > .1. Once again, even when they are given both statistical and speech cues to word boundaries, 6-month-olds fail to show any evidence of segmenting an artificial language. Therefore, as in Jusczyk and Aslin (1995), we fail to find any evidence that 6-month-olds can segment words from continuous speech.

General Discussion

   In Experiment 1, infants were familiarized with an artificial language containing no cues to word boundaries other than the transitional probabilities between syllables. The artificial language was identical to that used in Experiment 1 of Johnson and Jusczyk (2001). The test items, however, consisted of either the first two or last two syllables of a statistical word. We found that 8-month-olds recognized the last two syllables of a trisyllabic word more readily than they recognized the first two syllables. This finding was particularly interesting because all bisyllabic test items were defined by the same statistical structure (all syllable pairs were parts of statistical words). Therefore, we hypothesized that something other than the statistical structure of the artificial language may have affected infants' segmentation behavior. In particular, we suggested that infants' knowledge about English stress could have affected their segmentation

performance. In English, trisyllabic words containing three unreduced syllables typically have stress fall on the middle syllable (Burzio, 1994). If infants imposed stress on the second syllable of the trisyllabic words, then the latter two syllables would form a trochaic foot. Therefore, the last two syllables might be recognized more readily than the first two syllables because the first two syllables cross a foot-sized constituent.   We sought to further explore this hypothesis by testing 6-month-olds on these same bisyllabic test items. We were interested in testing these younger infants because current evidence suggests that 6-month-olds are not sensitive to how stress patterns in English (Jusczyk et al., 1993). Therefore, we predicted that if the effect observed in Experiment 1 was driven by language-specific understanding of English stress, then 6-month-olds should not recognize the ends of words more readily than the beginnings. Before we could test 6-month-olds on the stimuli used in Experiment 1, we wanted to make sure that 6-month-olds could segment an artificial language based on statistics alone. Experiments 2 through 4 failed to find any evidence that 6-month-olds can segment an artificial language. Therefore, we were unable to test 6-month-olds on the bisyllabic test items used in Experiment 1. It seems that testing infants (or adults) learning a language with a stress structure very different from English might be a better way to test the hypothesis presented in this study.

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