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Learning to Learn: Infants' Acquisition of Stress-Based Strategies for Word Segmentation

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A majority of English words are stressed on their first syllable. Infants use stress as a cue to word segmentation, but it is unclear how infants discover the correlation between stress and word boundaries. We exposed English-learning infants to a list of words stressed on their second syllable to discover whether infants can learn a new relation between stress and word boundaries. English-learning infants treat stressed syllables as word onsets, which is incorrect in words where stressed syllables occur second (iambic words). A brief exposure allowed infants to subsequently segment iambic words correctly, whether the exposure consisted of 100% or 80% iambic words. We also trained 7-month-olds—who typically rely on transitional probabilities—to use stress as a cue to word segmentation. The results suggest that infants are sensitive to the distribution of stress across word position and that altering this distribution affects their segmentation strategies.

Languages are complex systems characterized by multiple interdependent levels of organization, such as sound, meaning, and syntactic structure. And yet, infants, who are less cognitively advanced than adults, must learn them. At first glance, it seems surprising that languages are so complex given that cognitively immature infants must learn them. However, it may be the case that the complexity of language is not an obstacle for infants to overcome. The complexity of language may

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instead support and reinforce learning because organization at one level of language is correlated with organization at other levels of language. What infants learn about one aspect of language has the potential to help them learn about other aspects. For example, what infants learn about the phonemic inventory of their language is crucial for subsequently learning words (Werker & Curtin, 2005). Similarly, the phonotactic patterns that infants learn as they discover word-internal structure are later used to discover word boundaries in fluent speech (Mattys, Jusczyk, Luce, & Morgan, 1999). In each of these cases, acoustic structure provides cues to other aspects of linguistic organization.

As these examples suggest, learning a language requires, at least, two accomplishments for infants: first, identifying the patterns (e.g., acoustic regularities such as phonotactics) that occur in their language and, second, using these patterns as cues to facilitate learning at other levels of language. Recent research has provided rich insights into infants' ability to accomplish the first task, identifying patterns in their native language (e.g., Chambers, Onishi, & Fisher, 2003; Maye, Werker, & Gerken, 2002; Saffran, Aslin, & Newport, 1996). These experiments indicate that infants are sensitive to the frequency and distribution of events in their linguistic environment. For example, Maye et al. (2002) demonstrated that the distribution of phonemes that infants experience affects their discrimination of those phonemes. Infants are more likely to discriminate between a phonemic pair when exposed to a bimodal distribution, in which extreme exemplars of the two phonemes are most common. They are less likely to discriminate between two phonemes when exposed to a unimodal distribution, in which exemplars intermediate between the two phonemes occur most frequently.

But infants do more than just identify recurrent patterns in the language input; they also use those patterns to facilitate subsequent learning. Consider stress as an example: Stressed syllables are longer, louder, and higher pitched than unstressed syllables (Lieberman, 1960; for a discussion of the importance of syllables in early speech processing, see Bertoncini, Floccia, Nazzi, & Mehler, 1995). Words in English are likely to be stressed on their first syllable (Cutler & Carter, 1987), and infants prefer to listen to words that have this characteristic stress pattern by 9 months of age (Jusczyk, Cutler, & Redanz, 1993). In addition to recognizing the trochaic predominant stress pattern of English, infants also begin to use stress as a cue to word segmentation. Once infants identify the predominant pattern of English, they begin to treat stressed syllables as word onsets (e.g., Johnson & Jusczyk, 2001; Jusczyk, Houston, & Newsome, 1999). What infants have learned about the regularity of stress in English facilitates future learning, providing them with an additional cue to word boundaries (i.e., word boundaries come before a stressed syllable). Thus, as infants become familiar with their native language, they learn how to learn: Their learning becomes constrained by their previous experience and better suited to their native language.

Although a great deal of research has explored how infants are able to quickly learn from regularities in their environment (e.g., Chambers et al., 2003; Maye et al., 2002), little is known about the mechanisms that enable infants to use previous learning to facilitate and constrain subsequent learning (see Lany & Gomez, 2005). Returning again to the example of stress, infants' learning is facilitated by the discovery of a new cue to word boundaries (e.g., Jusczyk, 1999). Their learning is also constrained: Stress limits the range of potential segmentations, sometimes incorrectly, as in the case of words stressed on their second syllable (e.g., Jusczyk et al., 1999). In addition, infants incorporate information about stress into their representations of word forms; after hearing *DObita,* infants recognize that *doBIta* is different (Curtin, Mintz, & Christiansen, 2005). This information can influence subsequent word recognition and word segmentation. Our goal in this research is explore infants' discovery of stress as a cue to segmentation in order to better understand the parameters of infants' ability to utilize acoustic information to identify linguistic structure.

To use stress as a cue, infants must discover how stress corresponds with word boundaries (for a discussion of how differentiating stressed and unstressed syllables can facilitate use of transitional probabilities, Curtin et al., 2005). It is not enough for infants to detect that stressed and unstressed syllables tend to alternate in English. If this were all that they knew, the stressed syllables can indicate word beginnings, word middles, or word endings, or they can even occur randomly with respect to word boundaries. Mere perception of stress differences is not sufficient for word segmentation. Even 2-month-olds, who do not yet use stress as a cue to word segmentation, are able to detect the difference between stressed and unstressed syllables (Jusczyk & Thompson, 1978). To use stress as a cue to word segmentation, infants must learn how stress is correlated with word boundaries. Infants exposed to English identify this correlation by around 8 months, at which time they use stress as a cue to word segmentation (Johnson & Jusczyk, 2001; Jusczyk et al., 1999; Thiessen & Saffran, 2003). Though the developmental time course of infants' use of stress cues is well studied, there are several unanswered questions about the nature of their ability to discover the correlation between stress and word position: Do infants require prolonged exposure to language (e.g., 8 months) to identify such correlations, or can they be learned rapidly? Are infants who are younger than 8 months capable of such learning? What are the critical characteristics of the input that make this learning possible?

One possibility is that infants discover these correlations on the basis of words with which they are familiar. From the distribution of stress in these words, infants can identify how stress is related to word boundaries in their language. According to this account, infants' use of stress should be predictable from the rhythmic characteristics of the words to which they are exposed. If infants are primarily familiar with words that are stressed on their first syllable, they should associate stress with word onsets, as infants exposed to English do (Jusczyk et al., 1999). If infants are primarily familiar with words that are stressed on their last syllable, they should associate stress with word endings. Research by Polka and Sundara (2002) with French Canadian 8-month-olds is consistent with this prediction. Canadian infants exposed to French—a language in which words are not usually stressed on their first syllable—do not use stress as a cue to word beginnings. It is important to note that this distributional account is not the only possible explanation for infants' use of stress as a cue to word segmentation. For example, infants' rhythmic biases may arise from perceptual processing phenomena that do not require infants to learn from their native language (e.g., Trainor & Adams, 2000; van Heuven & Menert, 1996). However, if this is the case, it is difficult to account for infants' use of different rhythmic biases in different languages; for example, infants use stress as a cue to first syllable in English, whereas 8-month-olds exposed to French Canadian do not (Polka & Sundara, 2002). To assess the hypothesis that infants are sensitive to the distribution of stress in the words with which they are familiar, our experiments were designed to teach infants to use stress as a segmentation cue. By experimentally inducing a stress bias in infants, we can examine what infants learn from different input and whether certain types of input lead to different or better learning than other types. Importantly, we are not concerned solely with whether infants can learn novel acoustic patterns; previous research indicates that they are able to do so, even with relatively brief exposure (e.g., Chambers et al., 2003; Saffran & Thiessen, 2003). Rather, our goal is to understand how infants learn to use these acoustic patterns: how, once they have identified an acoustic pattern, they use that pattern to facilitate subsequent learning. Once infants have learned that words tend to begin with a stressed syllable, for example, they can begin to use stress as a cue to word boundaries in fluent speech. We hypothesize that infants can rapidly learn to use a new cue to word segmentation, if exposed to input that makes the relation between acoustic information and word boundaries clear.

To test this hypothesis, we employed a method that we have developed that allows us to simulate infants' experience with natural languages that exemplify different phonological patterns. In the pattern-induction method (Saffran & Thiessen, 2003), we first expose infants to a series of words separated by pauses and following a particular phonological pattern. The infants are then exposed to fluent speech that has no pauses but contains examples of the phonological patterns from the pattern-induction phase. If infants learn from the pattern-induction phase, this learning should influence the way that they subsequently segment the fluent speech. Finally, infants are tested on words from the segmentation phase versus similar nonwords to determine how they segment words from fluent speech. During the pattern-induction phase in the current set of experiments, English-learning infants were exposed to words stressed on their second syllable. If infants are capable of learning about the relationship between stress and syllable position within a word from the distribution of stress in the words with which they are familiar, they should learn a new relationship between stress and syllable position from our simulated language exposure. If this is the case, infants in our experiment should begin to use stress as a cue to word-final position. Experiments 1A and 1B are designed to assess whether 9-month-old infants can be taught to use stress in a novel manner (i.e., unlike English). Experiment 2 examines whether infants can learn from probabilistic information. Finally, in Experiment 3, we ask whether 7-month-old infants, who have failed to use stress as a cue to word segmentation in previous experiments using these fluent speech stimuli, begin to do so if they are exposed to our pattern-induction stimuli. These experiments, taken together, provide new insight not just into what infants can learn about how their language sounds but also into how they can begin to use that information to facilitate subsequent learning.

EXPERIMENT 1A

Most two-syllable words in English are trochaic (begin with a stressed syllable, followed by an unstressed syllable), and a majority of content words in English begin with a stressed syllable (Cutler & Carter, 1987). Infants exposed to English treat stressed syllables as word onsets by the time that they are 8 months old (Jusczyk et al., 1999): They prefer to segment strong–weak (trochaic) syllable sequences from fluent speech. Further, infants at this age incorrectly segment trochaic syllable sequences from fluent speech in which words have a weak–strong (iambic) pattern (Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003). For example, infants might segment *raffa* from the sequence *giraffe alone*.

Recent experiments have begun to explore the interaction between stress and one other important early cue to word boundaries: transitional probabilities. *Transitional probability* refers to the strength of the predictive relation between syllables: Through statistical learning, infants are likely to group and segment syllables that predict each other (Saffran et al., 1996). In fluent speech containing trochaic words, stress cues and transitional probabilities identify the same word boundaries. However, in fluent speech containing iambic words, stress cues and transitional probabilities identify different segmentation points. Consider again the phrase *giraffe alone*. Infants could segment a word like *giraffe* because the first syllable and the second syllable regularly co-occur (when an infant hears *gi*, they are likely to hear *raff* coming next). Alternatively, infants can segment the syllable sequence *raffa* because it is a trochaic (strong–weak) syllable sequence, even though the syllable *raff* does not predict the syllable *a* strongly: Infants hear many words other than *alone* after the word *giraffe*. As this example indicates, fluent speech containing iambic words presents infants with two potential segmentations: They can segment statistically coherent syllable sequences, or they can segment trochaic syllable sequences.

Previous research indicates that 9-month-olds segment trochaic syllable sequences from speech containing iambic words even in the presence of statistical cues that indicate an alternative segmentation possibility (Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003). When presented with the option to segment either statistically coherent sequences or trochaic sequences, 9-month-old infants treat stressed syllables as word onsets and segment trochaic sequences. This segmentation is inappropriate for iambic words: It leads infants to segment sequences that cross word boundaries (*raffa* in *giraffe alone*). The purpose of this experiment was to determine whether 9-month-old infants can learn to segment iambic speech correctly through exposure to words that are stressed on their second syllable. If infants can learn to apply an iambic segmentation strategy to fluent speech containing iambic words, they will segment items with high transitional probabilities (e.g., *giraffe* from the phrase *giraffe alone*).

If English-learning infants are unable to learn about iambs, which have a rhythmic pattern that contradicts the dominant pattern of English, they should continue to treat stress as a cue to word onsets. This will lead them to missegment fluent speech containing iambic words; they should mistakenly consider the stressed (second) syllables of iambic words as word beginnings. If, however, infants are able to learn from the pattern-induction stimuli, they should correctly segment an iambic language after experience with iambic words. We can test these contrasting predictions by exposing infants to a series of iambic words during the pattern-induction phase and then by asking them to segment fluent speech containing iambic words. If infants have learned to make use of the iambic stress pattern, they should now segment the fluent speech correctly.

Asking infants to segment iambic speech presents interpretational difficulties for experiments using the headturn preference procedure, which allows only for a comparison between infants' listening times to words and part-words (syllable sequences that cross word boundaries, such as "*tyba*" in the phrase "*pretty baby*"). When listening to iambic speech, infants hear a string of syllables, such as "diTI#buGO#daPU#doBI" (where the capitalized syllables represent stress in a series of two-syllable words—*diti*, *bugo*, *dapu*, and *dobi*—and the "#" marks word boundaries). During the testing session, infants are presented with test items such as "*diti*" (a word) and "*tibu*" (a part-word). Imagine that infants listen longer to part-words than to words. Does this indicate that infants have correctly segmented the language and showed a novelty preference for items that they (correctly) did not segment from fluent speech? Or does it indicate that infants incorrectly segmented the language and are showing a familiarity preference for part-words? This is an especially plausible interpretation because part-words are stressed on their first syllable in iambic fluent speech. Either interpretation is possible. Without knowing whether infants are likely to show a familiarity preference or a novelty preference, it is impossible to interpret such results. Further, predicting infant direction of preference a priori is quite difficult, because both novelty and familiarity preference regularly occur in experiments of this type (e.g., Thiessen, Hill, & Saffran, 2005).

To resolve this difficulty, we included an additional group of infants in Experiment 1A. These infants heard a list of trochaic words, rather than iambic words, during the pattern-induction phase (i.e., words with stress on the first syllable). The pattern-induction phase should reinforce infants' existing bias to treat stress as a cue to word onsets. These infants were then asked to segment fluent trochaic speech. We predicted that infants would segment trochaic syllable sequences from the trochaic fluent speech. Not only are these sequences statistically coherent, but the pattern-induction phase should reinforce infants' bias to segment trochaic sequences. For example, infants heard a stream of speech such as "DIti#BUgo#DApu#DObi," and we predicted that they would segment trochaic sequences such as "DIti" and "BUgo," rather than iambic sequences such as "ti#BU" or "go#DA." Iambic sequences violate the stress pattern infants expect; additionally, they are not statistically coherent. Because of this, infants should segment trochaic sequences. Because we had a strong prediction about infants' segmentation in the trochaic condition, we used the results of the trochaic condition as a baseline for interpreting the results of the iambic condition.

If infants in the iambic condition segment words (statistically coherent sequences) from the iambic fluent speech, they should show the same pattern of preference as infants in the trochaic condition. This indicates that both groups segmented the same items from fluent speech. Infants in the trochaic condition heard a stream of fluent speech such as "DIti#BUgo#DApu#DObi," from which they should segment words like "DIti" and "BUgo." Infants in the iambic condition heard a stream of fluent speech such as "diTI#buGO#daPU#doBI." If they segment trochaic items, they also segment different syllable sequences than do infants in the trochaic condition (e.g., part-words such as "TI#bu" and "GO#da"). However, if infants segment iambic items, they also segment words, as do infants in the trochaic condition. If infants in the iambic condition missegment the iambic fluent speech (i.e., if they segment part-words from the speech), then they should show the opposite pattern of preference as infants in the trochaic condition. For example, if infants in the trochaic condition listen longer to part-words, infants in the iambic condition should listen longer to words. Thus, with the baseline information from the trochaic condition available, it is possible to interpret the results from the iambic condition. Note, however, that this interpretation depends on the assumption that infants in the two conditions show the same direction of preference, an issue we address in Experiment 1B.

Method

Participants. Participants were 40 infants with a mean age of 9.04 months (range: 8.67 to 9.53). Twenty-three additional infants were excluded for the following reasons: fussing or crying (12); looking times of less than 3 s, on average, to either side light (4); parental interference (2); technical errors (2); failure to complete at least 8 out of 12 test trials (2); and experimental error (1). Of the 40 infants included in the final data analysis, 20 were randomly assigned to the trochaic condition, and 20 were randomly assigned to the iambic condition.

Stimuli. All stimuli were generated by the MacInTalk speech synthesizer. Two artificial languages were synthesized for use during segmentation, one iambic and one trochaic, each consisting of the same four bisyllabic nonsense words: “dapu,” “dobi,” “bugo,” and “diti.” Each language consisted of the same words spoken in the same randomized order. Two of the words occurred 60 times each, and the other two words occurred 30 times each, a feature that ensured that the two words and two part-words (syllable sequences that crossed word boundaries; the part-words in this experiment were formed across the boundaries of the two frequent words) used as test items occurred an equal number of times (Aslin, Saffran, & Newport, 1998). There were no pauses between words, and all syllables were fully coarticulated. The synthesizer produced syllables with a monotonic F0 of 200 Hz. We used CoolEdit and Kay Elemetrics’ Analysis and Synthesis Lab to alter the first syllables of words in the trochaic language and the second syllable of words in the iambic language. For both trochaic and iambic stress, we changed three parameters of the stimuli: vowel length, amplitude, and pitch (Lieberman, 1960). According to Crystal and House (1987), most of the syllable lengthening due to stress occurs on the vowels. Stressed vowels are increased by a much larger percentage (compared to unstressed vowels) than stressed consonants are increased compared to unstressed consonants. In addition, because stop consonants are much briefer than vowels, the absolute effect of stress lengthening on consonants is considerably smaller than vowel lengthening. As such, in our stimuli, we only increased the duration of vowels. Consonants were not lengthened, both because the absolute effect of consonant lengthening on the length of stressed syllables was small and because consonant lengthening can result in the extension of formant transitions, which can, in turn, make the consonants themselves more difficult to identify. Stressed vowels in our synthesized speech were lengthened to match Crystal and House’s estimates (1987) of the ratio of stressed vowels to unstressed vowels (range: 1.80:1 to 2.00:1; mean: 1.87:1). Thus, the stressed syllables were, on average, 310 ms long, and the unstressed syllables were all approximately 185 ms long. This ratio (1.67:1) is a close match with Crystal and House’s report (1990) of the ratio of stressed consonant–vowel (CV) syllables to unstressed CV syllables in the fluent speech of a fast talker (1.85:1). After the duration of the stressed syllables was altered, both the trochaic and the iambic language had a duration of one minute and thirty seconds.

Amplitude and fundamental frequency also increase in stressed syllables. Stressed syllables can have a peak amplitude between 4 dB and 8 dB higher than unstressed syllables (Bernstein-Ratner & Pye, 1984; Schwartz, Petinou, Goffman, Lazowski, & Cartusciello, 1995); the stressed syllables in this experiment were 4 dB louder than their unstressed counterparts. F0 values were based on the pitch contours of an adult female native speaker of English. Average pitch peak values varied from 255 Hz to 270 Hz, depending on the vowel. The pitch contour, resynthesized in stressed syllables using Kay Elemetrics' Analysis and Synthesis Lab, was somewhat different based on whether the syllable began with a voiced or an unvoiced consonant. In the case of a voiced consonant, the pitch contour was a roughly inverted parabola, whereas in the case of voiceless consonants, the pitch contour described a falling plateau. This is due to the fact that during the onset of a voiceless consonant, there are no glottal pulses and, thus, no F0 contour (Stevens, 1998). Therefore, when voicing began in the syllable, after a voiceless consonant, the value of the F0 was roughly where it would have been had the consonant been voiced, rather than starting at the ambient value (200 Hz). The beginning part of the pitch contour parabola has, in these cases, simply been cut off. Unstressed syllables remained at the monotonic pitch of 200 Hz at which they were synthesized.

Two lists—one iambic and one trochaic—were synthesized in citation form for use during the pattern-induction period. These lists consisted of 30 CVCV bisyllabic nonsense words (see appendix) repeated twice, for a total of 60 words, none of which were words or part-words from the segmentation languages. Though there were some repeated syllables in the list, approximately the same number of syllables (and types of syllables) occurred in first-syllable and second-syllable positions. There were pauses of 1.4 s between each word. The length of each list was 2 min and 6 s. These words were then edited to have either iambic or trochaic stress patterns. Unstressed syllables remained at the pitch (200 Hz), amplitude, and duration (272–327 ms, average 300 ms) values at which they were synthesized. Each individual stressed syllable was altered using CoolEdit and Kay Elemetrics' Analysis and Synthesis Lab to match the pitch, amplitude, and durational values of a native speaker articulating the same syllable in trochaic and iambic contexts. For both trochaic and iambic words, stressed syllables were lengthened to approximately 500 ms (range: 430–515 ms) and were increased in amplitude by 4 dB. The pitch peak of the stressed syllables was altered to achieve a maximal value of 267 Hz or 276 Hz, depending on the vowel. Pitch peaks were reached before the midway point of the vowel (usually by 40% of the vowel's steady state duration, somewhat earlier than the pitch peak of vowels in fluent speech) and lasted approximately 5% of the total length of the vowel. Pitch contour both rose and declined smoothly throughout the syllable, except during voiceless intervals, where there was no pitch contour (Stevens, 1998).

Infants were tested on their ability to discriminate words from part-words. The two part-words used during testing were formed across the two frequent words (i.e., *diti* and *bugo* formed the part-words "*tibu*" and "*godi*").[1] The two words used as test items were the infrequent words from the segmentation language (*dapu* and *dobi*); thus, all four test items (two words and two part-words) occurred equally often during familiarization (30 times). Because English-hearing infants prefer to listen longer to trochees than iambs (Jusczyk et al., 1993), all test items were presented with neutral stress during test trials. Infants in the trochaic and iambic conditions heard identical items during the test portion of the experiment. This design feature was necessary because if infants had heard the test items articulated in the same way during both the test trials and the familiarization period (i.e., with stress cues), they would have likely preferred to listen to the trochees, whether or not they had segmented these items from speech, complicating the interpretation of the data.

Procedure. Infants were tested individually in a double-walled sound-attenuated room while seated on a parent's lap. An experimenter outside the booth observed the infants' looking behavior on a video monitor connected to an infrared camera inside the room, and coded the direction of the infants' gaze online. The parent inside the room listened to masking music to eliminate bias, and the observer was similarly unable to hear the stimulus being played to the infant.

There were three phases of this experiment: pattern induction, word segmentation, and testing. During the pattern-induction phase, none of the room's lights were active. The infants sat on their caregivers' laps and listened to a list of 60 nonsense words (either trochaic or iambic) that played for 2 min from speakers on the left and right sides of the room simultaneously. Infants in the trochaic condition heard a list consisting of 30 trochaic words repeated twice, whereas infants in the iambic condition heard a list of 30 iambic words repeated twice.

At the beginning of the word segmentation phase, a light in the center of the wall facing the infant began to flash, directing the infant's gaze forward. Simultaneously, one of the two languages (either iambic or trochaic; the infants who heard the iambic pattern-induction stimuli heard the iambic segmentation language, and the infants who heard the trochaic pattern-induction heard the trochaic language) began to play simultaneously from both speakers beneath the two side lights—one light and speaker on each side wall—in the room. During this phase, the location of the flashing light was contingent on the infant's looking behavior. When the infant looked at the center light, one of the side lights began to flash and continued to flash for as long as the infant gazed in that direction. When the infant looked away from the side light for more than 2 s, that light extinguished and the center light be-

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[1] Here and throughout the article, words are defined by their statistical properties: Words are strings of syllables that always occur together. It is important to remember, though, that the items that infants segment from fluent speech are not necessarily words. For example, in the phrase *guitar is*, infants might well segment *taris* from fluent speech, because it has a strong–weak stress pattern.

gan to flash. During the word segmentation phase, the lights had no effect on the language: The segmentation language played continuously, regardless of the infant's looking behavior.

Immediately after the segmentation language ended, 12 test trials were presented. All infants heard the same test trials, regardless of condition. Six of these trials were part-word trials, and six were word trials. Each of the four test items occurred on three trials during the testing session. A test trial began with the blinking light at the center of the wall facing the infant, drawing the infant's gaze forward. When the observer signaled the computer that the infant had fixated on the center light, one of the side lights began to flash, and the center light simultaneously stopped. As soon as the infant made a head turn of at least 30 degrees in the direction of the flashing side light, the experimenter signaled the computer, and one of the test items was presented from the speaker beneath the flashing light. Test items were presented in random order, with six trials (three words, three part-words) presented from each side speaker. The test item continued to play for as long as the infant continued to look at the flashing side light. When the infant looked away for more than 2 s, the test item stopped playing, and the center light began to blink again. This procedure continued for as long as the infant was willing to attend or until they had completed all 12 test trials.

Results and Discussion

We first compared listening times to words and part-words for infants in the trochaic condition (i.e., infants who heard both the trochaic pattern-induction stimuli and the trochaic segmentation language). Recall that in the trochaic condition, words are syllable sequences that are both trochaic and statistically coherent, whereas part-words are neither. As shown in Figure 1, infants listened to words for 6.4 s (*SE* = 0.6 s) during the test trials and to part-words for 7.5 s (*SE* = 0.6 s). Fifteen of the 20 infants listened longer to part-words than to words during the test trials after exposure to the trochaic language. A paired *t* test (all *t* tests reported are two-tailed) indicated that the difference in looking times between words and part-words was significant: $t(19) = 2.17$, $p < .05$. Nine-month-old infants showed a novelty preference for part-words over words after listening to the trochaic language. This establishes that, as expected, infants are able to successfully segment the trochaic language. To assess the results of infants' word segmentation in the iambic condition, we compared their listening time to words and part-words. In the iambic condition, words were still statistically coherent but were heard as iambs (weak–strong sequences) during the familiarization phase. Part-words were not statistically coherent but were heard as trochees (strong–weak sequences) during the familiarization phase. As shown in Figure 1, infants listened to words for 5.6 s (*SE* = 0.3 s) during the test trials and to part-words for 6.6 s (*SE* = 0.6 s). Fourteen of the 20 infants listened longer to

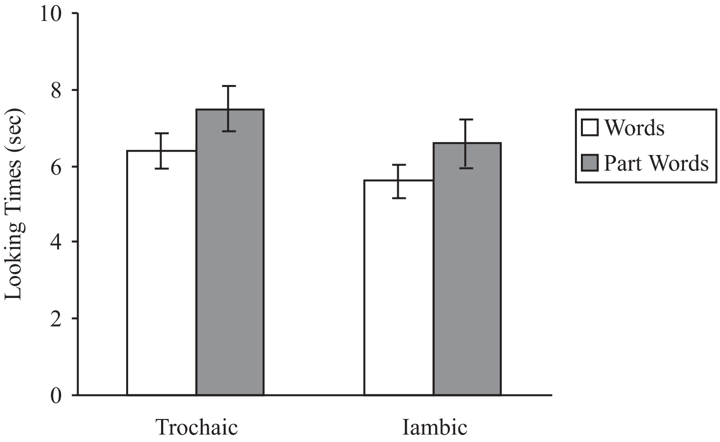

FIGURE 1 Nine-month-old infants' looking times to words and part-words in the trochaic and iambic conditions of Experiment 1.

part-words than to words during the test trials after exposure to the iambic language. A paired *t* test indicated that the difference in looking times between words and part-words was significant: $t(19) = 2.15$, $p < .05$.

Although infants' looking times after exposure to the trochaic pattern-induction were somewhat longer than their looking times after exposure to the iambic pattern-induction, an analysis of variance indicated that this difference was not significant. Although the iambic pattern-induction materials certainly violated infants' expectations for where stress should appear in words, this did not appear to affect their responses. Instead, infants in both the iambic and the trochaic condition showed the same pattern of preference, with both groups looking longer to part-words than to words. The identical pattern of preference in the two groups suggests that they segmented the same items from both the iambic and the trochaic fluent speech. In previous experiments using these same languages, infants segmented different items from trochaic fluent speech than from iambic fluent speech and showed opposite patterns of preference (Thiessen & Saffran, 2003). The reason is that infants have a bias to segment stressed–unstressed units from fluent speech. This has lead them to segment different items from fluent speech made up of trochaic words (where stressed–unstressed sequences are words) and from fluent speech made up of iambic words (where stressed–unstressed sequences cross word boundaries). In the current experiment, in which infants demonstrated the same pattern of preference in both conditions, infants appeared to have segmented the same items from both the trochaic and the iambic fluent speech. This indicates that infants learned from the iambic pattern-induction materials and used a segmentation strategy that was appropriate (i.e., lead to the segmentation of words) to the iambic fluent speech.

However, an alternative possibility is that infants showed a different direction of preference in the two conditions: a novelty preference in the trochaic condition and a familiarity preference in the iambic condition. A different direction of preference means that infants segmented different items from the two languages (and missegmented the iambic fluent speech). This is an especially plausible hypothesis because, of the two languages, the iambic one may be more difficult to segment, given that the two available cues to word boundaries—transitional probabilities and stress—indicate different segmentation points. These conflicting cues present the possibility that iambic fluent speech may be more difficult for infants to segment. Previous research indicates that in tasks with different degrees of difficulty, the more difficult task can result in a familiarity preference, whereas the easier task leads to a novelty preference (e.g., Hunter & Ames, 1988). Therefore, to interpret the results of Experiment 1A, we need to more firmly establish that infants showed the same direction of preference in both conditions—in particular, that they showed a novelty preference in the iambic condition. This was the goal of Experiment 1B.

EXPERIMENT 1B

In the absence of iambic pattern-induction materials, infants segment part-words from fluent speech containing iambic words (Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003). This is due to the fact that infants treat stressed syllables as word onsets, whereas in iambic words, stressed syllables are the second syllables of words. If we present infants with fluent iambic speech without giving them any exposure to iambs during the pattern-induction period, they should missegment the iambic speech and segment part-words. Though transitional probabilities and stress cues conflict (for infants with a trochaic bias) in iambic fluent speech, previous research (Johnson & Jusczyk, 2001) has demonstrated that infants favor stress cues. Because we have a prediction about the items that infants should segment from the fluent speech, we can assess direction of preference.

Infants in this experiment were first exposed to a trochaic pattern-induction phase so that the experiment would be of the same length as the conditions in Experiment 1A. This pattern-induction phase should reinforce their trochaic bias. They were then asked to segment iambic fluent speech. Infants should segment part-words from the fluent speech because their trochaic segmentation bias will not lead them to correctly segment iambic fluent speech (Johnson & Jusczyk, 2001). If they listen longer to part-words during the test trials, this will indicate a familiarity preference. If they listen longer to words, this will indicate a novelty preference. If infants in this experiment show a novelty preference, it will strengthen the interpretation that infants in the iambic condition of Experiment 1A did so as well. This is important because the conclusion that infants in both conditions of Experiment 1A segmented the same items from fluent speech rests on the validity of the assumption that infants showed a novelty preference in both conditions.

Method

Participants. Participants were 20 infants with an average age of 8.99 months (range: 8.53 to 9.50). An additional 11 infants were excluded for the following reasons: looking times of less than 3 s, on average, to either side light (4); failure to complete at least two of one or more trial types (4); and fussing or crying (3).

Stimuli. Infants heard the trochaic pattern-induction stimuli from Experiment 1A and the iambic fluent speech from Experiment 1A. The test items were identical to those used in Experiment 1A.

Procedure. The procedure was identical to that of Experiment 1.

Results and Discussion

We compared listening times to words and part-words for infants exposed to the trochaic pattern-induction stimuli followed by the iambic segmentation language. Recall that words were statistically coherent in the segmentation language but stressed on their second syllable. Part-words had low transitional probabilities but a trochaic stress pattern. Infants listened to (statistically coherent) words for 6.6 s ($SE = 0.6$ s) during the test trials and to part-words for 5.8 s ($SE = 0.5$ s). Fourteen of the 20 infants listened longer to words than to part-words during the test trials after exposure to the trochaic language. A paired t test indicated that the difference in looking times between words and part-words was significant: $t(19) = 2.31$, $p < .05$.

In previous research using this iambic language (Thiessen & Saffran, 2003), infants segmented the part-words from fluent speech because part-words were stressed on their first syllable. Given these earlier results with the same language, we can conclude that infants in the current experiment also segmented part-words from the fluent speech. Transitional probabilities (which indicate words as a segmentation choice) and stress cues (which indicate part-words) conflicted, and infants relied on their trochaic bias to segment part-words (Johnson & Jusczyk, 2001). This is the result that we predicted, because their trochaic bias was reinforced by the trochaic pattern-induction stimuli and led them to segment part-words. The fact that infants in the current experiment listened longer to words indicates that infants displayed a novelty preference: They listened longer to the items that they did not segment from fluent speech. The current results argue that the potential increased difficulty of segmenting iambic fluent speech was not enough to cause infants in the current series of experiments to show a familiarity preference. Rather, these results support the claim that infants showed a novelty preference in the iambic condition of Experiment 1A, as well as in the trochaic condition.[2]

EXPERIMENT 1 SUMMARY

In Experiment 1A, infants showed the same pattern of preference (listening longer to part-words) in both the trochaic and the iambic condition. The results of Experiment 1B suggest that infants showed a novelty preference in both conditions of Experiment 1A. Therefore, the fact that infants showed the same pattern of preference in both conditions indicated that they segmented the same syllable sequences from both the trochaic and the iambic fluent speech. Because infants are likely to have segmented words (statistically coherent syllable sequences) from the trochaic fluent speech, we can assume that infants also segmented words from the iambic fluent speech. If this is the case, then infants must have learned about iambic stress cues from the iambic pattern-induction phase. Instead of segmenting items with a strong–weak pattern (part-words) from the fluent iambic speech, as they do in the absence of an iambic pattern-induction phase, they segmented items with a weak–strong pattern (words). These results suggest that the iambic pattern-induction materials counteracted infants' preexisting trochaic bias in the iambic condition.

This is quite striking, because 9-month-old infants usually segment part-words when listening to fluent speech composed of iambic words (e.g., Johnson &

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[2] An alternative hypothesis is that infants failed to segment words in either Experiment 1A or Experiment 1B. Instead, they may have only detected stressed syllables in the fluent speech. If so, infants' experience with English, in which stressed syllables tend to occur at the beginnings of words, may have caused them to treat test items that began with a stressed syllable (words in the trochaic segmentation language; part-words in the iambic segmentation language) as most similar to the fluent speech. In addition, infants may have shown a novelty preference after exposure to the trochaic pattern induction—which is similar to English—and a familiarity preference after exposure to the iambic pattern induction. If this were the case, infants would prefer words in the trochaic and iambic condition of Experiment 1A and part-words in Experiment 1B. This hypothesis suggests that infants did not learn from the pattern-induction phase; indeed, they did not even segment words from fluent speech. Note, though, that this hypothesis presumes that infants have a preexisting trochaic bias: They prefer test items in which the stressed syllables they represent occur in word-initial position. In Experiment 3, we demonstrate that younger infants, who in previous experiments of this type did not demonstrate a trochaic segmentation strategy (Thiessen & Saffran, 2003), learn from the pattern-induction materials. In addition, this hypothesis is incompatible with recent research demonstrating that infants represent the phonetic content of unstressed syllables (Johnson, 2005). As such, the most plausible explanation is that infants in Experiment 1 segmented words from fluent speech.

Jusczyk, 2001). Moreover, infants in our prior experiments missegmented the iambic language used in Experiment 1A when exposed to it without a pattern-induction phase (Thiessen & Saffran, 2003). If infants segmented words from fluent speech in the iambic condition of Experiment 1, it would have meant that the iambic pattern-induction phase changed their word segmentation. One way in which the pattern-induction phase could influence segmentation is that it could have provided the infants with an opportunity to learn that words can be stressed on their second syllable.

However, this demonstration of infants' learning cannot be easily generalized to an infant's natural environment, for several reasons. One of these is that the pattern-induction stimuli consisted entirely of iambic words. Most acoustic patterns that infants must learn are less regular. For example, although most words in English begin with a stressed syllable, there are a number of words that begin with an unstressed syllable. If the learning that infants displayed in Experiment 1 is comparable to that of infants who are learning from the predominantly (but not entirely) stress-initial pattern of English, infants ought to be able to learn about a rhythmic pattern from exposure to words that usually, but do not always, follow the same pattern.

EXPERIMENT 2

To explore the hypothesis that infants can learn from probabilistic input, we altered the iambic pattern-induction stimuli from Experiment 1. In Experiment 1, the pattern-induction stimuli consisted of 30 words (repeated twice), all of which were iambic. In the current experiment, the pattern-induction stimuli consisted of 30 words, only 24 of which were iambic; the other 6 words were trochaic. If infants are able to extract the dominant pattern from mostly regular input, these pattern-induction stimuli should suffice. If, however, infants require deterministic input, infants should fail to extract information about an iambic stress pattern from this exposure and maintain their trochaic segmentation bias. This, in turn, would lead them to missegment fluent speech containing iambic words.

Method

Participants. Participants were 40 infants with an average age of 9.19 months (range: 8.77 to 9.47). An additional 18 infants were excluded for the following reasons: looking times of less than 3 s, on average, to either side light (11); fussing or crying (5); computer failure (1); and failure to complete at least two of one or more trial types (1). Of the 40 infants included in the final data analysis, 20 were randomly assigned to the trochaic condition, and 20 were randomly assigned to the iambic condition.

Stimuli. As in Experiment 1A, there was both a trochaic and an iambic condition. However, unlike those in Experiment 1A, only 24 of the 30 words presented during pattern-induction showed the predominant stress pattern; the other 6 had the opposite pattern. We chose 80% regularity because previous experiments (Gomez & Lakusta, 2004; Saffran & Thiessen, 2003) have indicated that infants have difficulty learning from stimuli that are less than 67% regular, at least given a relatively brief exposure period. In the iambic condition, instead of a list of 30 iambic words, only 24 of the words in the list were iambic. The other 6, including the first word and the last word, were trochaic, spread at approximately equal intervals throughout the list. These 6 trochaic words were taken from the trochaic pattern-induction stimuli of Experiment 1 and spliced into the new pattern-induction sound file. The infants heard the resulting list of 30 words twice so that the entire pattern-induction period had a duration of 2 min and 6 s. The trochaic pattern-induction stimuli were created in exactly the same way: 24 of the words had a trochaic stress pattern, and the other 6 had an iambic pattern.

The segmentation languages and test items were identical to those used in Experiment 1. Infants in the trochaic condition heard the trochaic pattern-induction stimuli and the trochaic segmentation language, and infants in the iambic condition heard the iambic pattern-induction stimuli and the iambic segmentation language. The test items in both conditions were identical.

Procedure. The procedure of this experiment was identical to that used in Experiment 1.

Results and Discussion

First, we compared listening times to words and part-words for infants in the trochaic condition. Given the results of Experiment 1, we predicted that infants in this experiment would also show a novelty preference. Recall that in the trochaic condition, words were syllable sequences that were both trochaic and statistically coherent, whereas part-words were neither. As shown in Figure 2, infants listened to words for 5.9 s ($SE = 0.5$ s) during the test trials and to part-words for 7.0 s ($SE = 0.4$ s). For infants showing a novelty preference, listening longer to part-words indicates that they segmented words. Fourteen of the 20 infants listened longer to part-words than to words during the test trials after exposure to the trochaic language. A paired *t* test indicated that the difference in looking times between words and part-words was significant: $t(19) = 2.87$, $p < .05$. Nine-month-old infants showed a novelty preference for part-words over words after listening to the trochaic language.

Next, we analyzed infants' listening times to words and part-words in the iambic condition. In the iambic condition, words were statistically coherent but were heard as iambs (weak–strong sequences) during the familiarization phase.

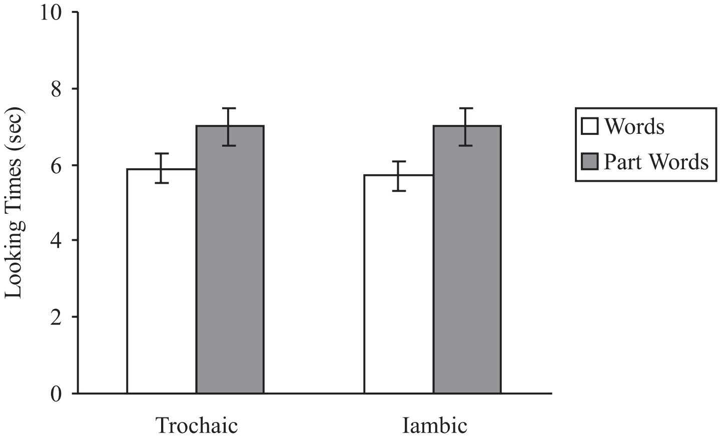

FIGURE 2 Looking time to words and part-words in the trochaic and iambic conditions of Experiment 2.

Part-words were not statistically coherent but were heard as trochees (strong–weak sequences) during the familiarization phase. As shown in Figure 2, infants in this experiment listened to words for 5.7 s (*SE* = 0.4 s) and to part-words for 7.0 s (*SE* = 0.6 s). For infants showing a novelty preference, listening longer to part-words indicates that they segmented words. Sixteen of the 20 infants listened longer to part-words than to words during the test trials after exposure to the trochaic language. A paired *t* test indicated that the difference in looking times between words and part-words was significant: $t(19) = 2.51$, $p < .05$.

Infants in this experiment showed the same pattern of preference in both the trochaic and the iambic condition. Remember that the results of Experiment 1 indicate that infants should show a novelty preference in both trochaic and iambic conditions. If infants continued to show the same direction of preference, the fact that infants showed the same pattern of preference in both conditions indicates that they segmented the same items (words) from both the trochaic and iambic fluent speech. For infants to segment the iambic language correctly, they must have learned from the iambic pattern-induction stimuli. In this experiment, infants altered their use of stress as a cue to word segmentation after an exposure that consisted of mostly—but not entirely—iambic words. Infants can learn about the relationship between stress cues and word boundaries from probabilistic input. This result is consistent with the hypothesis that the learning process tapped in these experiments is relevant to the acquisition of natural languages, which are largely characterized by probabilistic patterns.

There are two ways in which the pattern-induction stimuli may have affected infants' subsequent word segmentation in these experiments, and either of them would have allowed infants to segment iambic fluent speech correctly. First, infants may have discovered that stress is an unreliable cue to word boundaries. Before the pattern-induction phase, infants were biased to treat stress as a cue to the first syllables in words. However, the pattern-induction phase provided infants with evidence that stress occurs on the second syllable of words. Confronted with experience that contradicted their bias, infants may have ceased to rely on stress and instead used transitional probabilities to segment fluent speech. Using transitional probabilities would have allowed infants to segment the iambic fluent speech correctly. Alternatively, infants could have learned a novel rhythmic bias. The pattern-induction materials may have taught infants to treat stress as a cue to the second syllable of words. This novel rhythmic bias would have also allowed infants to segment the iambic fluent speech correctly. This second possibility more closely matches the learning that infants achieve when faced with natural languages: identifying a novel cue and beginning to use it. If the distributional hypothesis is correct and infants initially learn to use stress as a cue to word segmentation by attending to the correlation between stress and syllable position (e.g., word-initial) in words with which they are familiar, it should be possible to demonstrate such learning in this experiment. That is, infants should be able to learn a novel segmentation strategy rather than just learn to rely on transitional probabilities. This type of learning allows infants to discover that stress predicts the first syllables of words in English. Several converging results indicate that infants exposed to English begin to use stress as a cue to word segmentation around 8 months (e.g., Echols, Crowhurst, & Childers, 1997; Jusczyk et al., 1999; Thiessen & Saffran, 2003). These results suggest that some time before 8 months, infants must be able to discover that stress is a predictive cue in their environment and begin to use it for the first time. This is the prediction that we evaluate in Experiment 3.

EXPERIMENT 3

Thiessen and Saffran (2003) found that infants between 6 months and 7 months of age do not use stress as a cue to word boundaries when they are exposed to fluent speech that contains both stress and statistical cues, though 7-month-old infants are sensitive to stress in experimental situations where statistical cues have been removed (Curtin et al., 2005). Infants at this age attend primarily to transitional probabilities and, as such, do not missegment fluent speech containing iambic words. In Experiment 3, we asked whether 7-month-old infants would begin to use an iambic segmentation strategy after exposure to iambic pattern-induction materials. That is, can we teach these young infants to begin to use stress as a cue to word boundaries in these languages? To assess this question, we presented infants with the iambic pattern-induction stimuli from Experiment 1, followed by the trochaic segmentation language. If our pattern-induction materials can teach infants a new stress-based segmentation strategy, then infants in this experiment should missegment the trochaic fluent speech. They should learn, from the pattern-induction stimuli, that stress is a cue to the second syllables of words. This should cause them to missegment trochaic fluent speech. For example, in the string of trochaic words "*DIti#BUgo#DApu*," the part-words "*tibu*" and "*goda*" are stressed on their second syllables. If infants learn to treat stressed syllables as second syllables, they should segment part-words from trochaic fluent speech.

As we did in Experiments 1 and 2, we included two groups of infants to facilitate interpretation of the data. One group of infants heard the iambic pattern-induction stimuli and then fluent iambic speech. A second group heard the iambic pattern-induction stimuli and then fluent trochaic speech. If infants segment the same items from both the trochaic and the iambic fluent speech, then they relied on the cue to word boundaries that is the same across the two languages: transitional probabilities. This would indicate that infants did not learn to use stress as a cue to word boundaries. However, if infants show different patterns of preference after hearing the iambic and trochaic fluent speech, then the pattern-induction period must have affected their subsequent segmentation. This would indicate that they have relied on a cue—stress—that they did not previously use.

Method

Participants. Participants were 31 infants with an average age of 6.92 months (range: 6.50 to 7.53). An additional 10 infants were excluded for the following reasons: looking times of less than 3 s, on average, to either side light (8); failure to complete at least two of one or more trial types (1); and experimental error (1). Of the 31 infants included in the final data analysis, 15 heard iambic pattern-induction materials followed by iambic fluent speech, whereas 16 heard iambic pattern-induction materials followed by trochaic fluent speech.

Stimuli. All infants first heard the iambic pattern-induction stimuli from Experiment 1. Next, half of the infants heard the fluent iambic speech from Experiment 1, whereas the other half heard the fluent trochaic speech from Experiment 1. Test items were identical to those in Experiments 1 and 2.

Procedure. The procedure was identical to Experiment 1.

Results and Discussion

We first compared listening times to words and part-words for infants exposed to the iambic pattern-induction stimuli followed by the iambic segmentation task. Recall that words were statistically coherent items but, in this experiment, were stressed on their second syllables during the fluent speech. Given the results of Experiment 1, we predicted that infants would show a novelty preference. As shown in Figure 3, infants listened to words for 6.4 s (*SE* = 0.6 s) during the test trials and to part-words for 8.1 s (*SE* = 0.7 s). For infants showing a novelty preference, listening longer to part-words indicates that they segmented words from the fluent speech. Twelve of the 15 infants listened longer to part-words than to words during the test trials after exposure to the fluent iambic speech. A paired *t* test indicated that the difference in looking times between words and part-words was significant: $t(14) = 4.34$, $p < .05$.

We next assessed the performance of the infants exposed to the iambic pattern-induction stimuli followed by the trochaic segmentation task. As shown in Figure 3, infants listened to words for 7.9 s (*SE* = 0.7 s) during the test trials and to part-words for 6.2 s (*SE* = 0.7 s). For infants showing a novelty preference, listening longer to words indicates that they segmented part-words from the fluent speech. In this condition, part-words were not statistically coherent but were stressed on their second syllable (consistent with an iambic segmentation bias). Thirteen of the 16 infants listened longer to words than to part-words during the test trials after exposure to the iambic language. A paired *t* test indicated that the difference in looking times between words and part-words was significant: $t(15) = 2.21$, $p < .05$.

To establish that infants' patterns of preference in the two conditions were significantly different, we performed a 2 × 2 (Condition × Item) ANOVA. There was no significant effect of segmentation language (iambic versus trochaic): $F(1, 29) = 0.95$, $p > .10$. There was also no significant effect of item (word versus part-word): $F(1, 29) = 0.01$, $p > .10$. There was, however, a significant condition by item interaction: $F(1, 29) = 14.87$, $p < .05$. The preference for part-words over words that in-

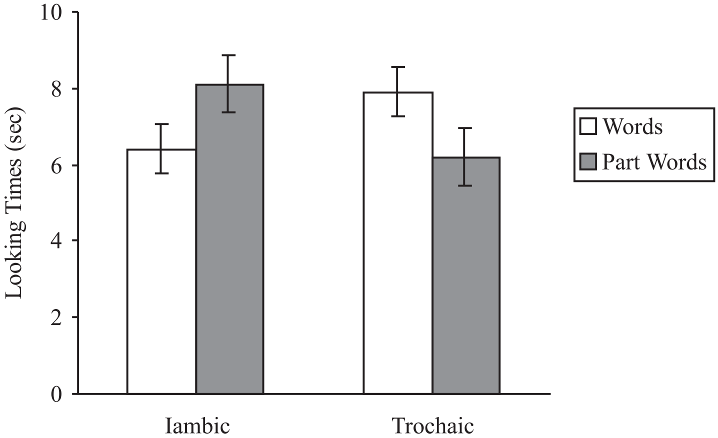

FIGURE 3 Seven-month-old infants' looking times to words and part-words after listening to iambic fluent speech or trochaic fluent speech in Experiment 3.

fants showed after listening to iambic fluent speech was significantly different from their preference for words after listening to trochaic fluent speech.

In previous research with the same fluent trochaic and iambic speech used in this experiment, 6- to 7-month-old infants segmented the same items from both languages (Thiessen & Saffran, 2003). In this experiment, though, the presence of the iambic pattern-induction materials led infants to show a different pattern of preference after hearing trochaic and iambic fluent speech, indicating that they segmented different items from iambic fluent speech than from trochaic fluent speech. This suggests that the iambic pattern-induction period led infants to employ a new iambic rhythmic segmentation strategy. If infants attended to statistical cues, they would have segmented the same items from both languages and shown the same pattern of preference. The fact that infants showed a different pattern of preference indicates that infants developed an iambic segmentation bias. This segmentation bias was appropriate for iambic fluent speech and allowed infants to segment correctly in the iambic-iambic condition. However, it led infants to missegment trochaic fluent speech, where words were stressed on their first syllable. Instead of segmenting words from the trochaic fluent speech, infants segmented part-words, which were stressed on their second syllable, consistent with the rhythmic pattern of the iambic pattern-induction materials.

These results are important because, unlike the results of Experiments 1 and 2, they cannot be interpreted as a sign that infants have ceased to use stress as a cue to word segmentation and relied instead on transitional probabilities. The transitional probabilities between syllables are identical in the trochaic and iambic fluent speech. If infants had relied on transitional probabilities, they would have segmented the same items from both types of fluent speech. Instead, the current results could only have occurred if infants learned a new rhythmic segmentation bias. This is especially striking because without the pattern-induction materials, infants do not use stress as a cue to word segmentation in experiments where transitional probabilities are available (Thiessen & Saffran, 2003). The pattern-induction phase caused these young infants to employ a new segmentation strategy.

GENERAL DISCUSSION

The results of these experiments, taken together, suggest that infants can learn about the stress pattern of language from exposure to words. Experiencing a novel correlation between stress and syllable position within a word led infants to change the way that they responded to stress as a cue to word boundaries. They began to use stress as a cue to word endings rather than as a cue to word beginnings. These experiments support the claim that the trochaic bias develops from infants' experience with the distribution of stress in English. Exposure to a language with a different correlation between stress and word position (such as a language where stress consistently occurs at the end of words) should lead to a different segmentation bias. Our experiments directly test and strongly support the hypothesis that has emerged from more naturalistic studies (e.g., Jusczyk et al., 1999; Polka & Sundara, 2002), namely, the existence of a learning mechanism that responds to the distribution of stress in the words with which infants become familiar as they learn their language.

If it is the case that the distribution of stress in words teaches infants to use stress as a cue to word segmentation, it may seem initially surprising that 6- to 7-month-old infants would fail to use stress to segment the fluent speech used in these experiments (Thiessen & Saffran, 2003). They have had, after all, at least 6 months of experience with English. This could give infants ample time to discover that stress is a good cue to word boundaries and to begin to use stress as a cue to the first syllables of words. According to the distributional account, however, simply hearing the alternation of stressed and unstressed syllables in a language does not provide infants with enough evidence to acquire a trochaic (or iambic) bias. Infants must first learn some words—a task that 6-month-old infants may not yet have accomplished—to discover how stress is correlated with word boundaries in their language. The pattern-induction materials in these experiments provided infants with concentrated experience with words in isolation, in a manner unlike what they are exposed to in the course of normal experience. The fact that 6- to 7-month-old infants are able to acquire a rhythmic bias so quickly, given appropriate experience, supports the hypothesis that experience with words plays an important role in the development of a language-appropriate rhythmic bias.

As these experiments demonstrate, one source of information about the correspondence between words and stress is exposure to words in isolation. Though learning from isolated words is likely easier for infants, the majority of words to which infants are exposed come in the form of fluent speech (Brent & Siskind, 2001). Although 6-month-olds have a great deal of experience listening to English, they have likely segmented very few words from fluent speech (Jusczyk & Aslin, 1995). These considerations suggest that statistical learning may play an important role in the development of a rhythmic segmentation bias. Attention to transitional probabilities, a type of statistical learning (Saffran et al., 1996), could potentially provide infants with a way of identifying several of the words in fluent speech to which they are exposed. A recent corpus analysis (Swingley, 2005) has demonstrated that using statistical segmentation mechanisms would provide infants with an inventory of co-occurring syllables that have the predominant strong–weak stress pattern of English. The proposal that statistical learning provides infants with an inventory of words, from which they can discover that stress predicts word onsets, predicts that attention to transitional probabilities is a word-segmentation strategy that precedes attention to stress. This prediction is consistent with the results of Thiessen and Saffran (2003). In that experiment, 6- to 7-month-old infants relied on transitional probabilities, rather than stress, to segment fluent speech. Although statistical learning and acoustic cues (such as stress) have often been conceptualized as different approaches to segmenting fluent speech, it may be the case that they are deeply interconnected. Importantly, the relation between statistical learning and acoustic regularities in speech may be cyclical and reinforcing. Just as statistical learning allows infants to identify acoustic regularities, infants' representation of acoustic information may constrain statistical computations and make them more informative (Curtin et al., 2005).

Though these results demonstrate that infants can learn from information about the distribution of stress in their environment, there are several additional challenges presented by natural input that are important to consider. For example, the segmentation stimuli used in this experiment consisted entirely of bisyllabic words. By contrast, infants learning English are exposed, in addition, to monosyllabic words and words with three or more syllables. The majority of these words begin, as do most words in English, with a stressed syllable (e.g., Cutler & Carter, 1987). However, they do not always exemplify the same, overregular alternation between stressed and unstressed syllables as the bisyllabic words used in these experiments. Two stressed monosyllabic words occurring in sequence would, for example, present infants with quite a different opportunity for segmentation than would a trisyllabic word with primary stress on the first syllable and secondary stress on the third syllable. Though we did not examine this source of variability in the current experiments, recent research suggests that infants' rhythmic segmentation strategies—and thus, potentially, their ability to learn about rhythm as a cue to segmentation—are not limited to bisyllabic words. Infants use stress to segment a wider variety of words from fluent speech than canonical bisyllabic trochees (Houston, Santelmann, & Jusczyk, 2004).

Another way in which these experiments differ from natural languages is that infants in this experiment were only exposed to one stress pattern when they were segmenting words from fluent speech. Infants must eventually succeed in segmenting both iambic and trochaic words (and words with other rhythmic patterns), not just one or the other (e.g., Jusczyk et al., 1999). It may be the case that older infants—who can successfully segment iambic words—do so by relying on a wider variety of cues rather than solely on stress. Multiple cues are likely to better indicate word boundaries than any single cue (Christiansen, Allen, & Seidenberg, 1998; Jusczyk, 1999). Morgan and Saffran (1995) have demonstrated that older infants are more successful than younger infants at integrating multiple cues to word segmentation. Similarly, research by Thiessen and Saffran (2004) indicates that older infants are less reliant on stress alone as a cue to word segmentation. Both of these results are consistent with the hypothesis that infants eventually succeed in segmenting words that violate their trochaic expectations by integrating multiple cues to segmentation.

Clearly, the increased variability in natural languages, as compared to the patterns that infants were familiarized with in these experiments, presents a challenge for learning. Infants are never presented with a list of words that all follow one phonetic pattern. At the same time, of course, infants have much more exposure to natural language, and thus presumably more opportunity for learning, than what they receive in the few minutes of these experiments. The current experiments demonstrate that infants are capable of learning to identify rhythmic regularities in the input and begin to use them for segmentation. This type of learning allows infants to learn effectively in many different linguistic situations, even though different languages and linguistic environments present different regularities (e.g., Polka, Sundara, & Blue, 2002).

Although there are many remaining questions to be explored, the current results provide some insight into the mechanisms that allow infants to identify correlations between acoustic and lexical structure. They indicate that familiarity with words can affect infants' rhythmic biases, leading them to use novel rhythmic segmentation strategies. Infants are not engaged simply in learning what acoustic patterns occur in their language (e.g., Chambers et al., 2003; Maye et al., 2002). Instead, they detect correlations between acoustic structure and other aspects of language, which allows acoustic regularities to serve as a cue to other aspects of learning. This detection of correlations may be another kind of statistical learning. Just as infants are sensitive to the probabilities of syllables predicting each other within and across word boundaries, they may be sensitive to the probability of an acoustic phenomenon (stress) predicting word position: first syllables in English and other syllables in languages where stress occurs in different word positions. The detection of correlations between acoustic structure and word boundaries need not be limited solely to stress. It may be involved in the acquisition of several acoustic regularities that serve as cues to word position (e.g., phonotactics, allophonic variation). The discovery of these regularities, in turn, allows infants to better and more reliably segment words from fluent speech, because no single cue to word boundaries is as informative as a combination of cues (Christiansen et al., 1998; Jusczyk, 1999).

These experiments suggest that the learning that results from one process (discovering stress patterns) can affect another learning process (word segmentation). Becoming familiar with words allows infants to discover acoustic regularities associated with different word positions. This type of multilevel learning could be important for many aspects of language acquisition, not just word learning (e.g., Saffran & Wilson, 2003). Further, this type of multilevel learning has implications for our understanding of infants' ability to learn. To the extent that the results from learning at one level of language are important to progress at other levels, explorations of individual components of language acquisition in isolation may underestimate the breadth and flexibility of infants' language learning abilities.

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APPENDIX

Words used in the pattern-induction phase of Experiments 1–3 (all words used for both iambic and trochaic pattern induction).

baga
giku
koga
pabu
talaw
piro
podu
kabee
lidoe
tookaw
rapee
gadoe
koogaw
bagee
kodaw
poolaw
leekaw
gapee
geebow
toolaw
daree
bidoo
pabaw
koree
lapoo
baloo
rowkow
ratee
gabee
leetaw