Cognitive Psychology **39,** 159–207 (1999)
Article ID cogp.1999.0716, available online at http://www.idealibrary.com on IDEAL®

The Beginnings of Word Segmentation in English-Learning Infants

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A series of 15 experiments was conducted to explore English-learning infants' capacities to segment bisyllabic words from fluent speech. The studies in Part I focused on 7.5 month olds' abilities to segment words with strong/weak stress patterns from fluent speech. The infants demonstrated an ability to detect strong/weak target words in sentential contexts. Moreover, the findings indicated that the infants were responding to the whole words and not to just their strong syllables. In Part II, a parallel series of studies was conducted examining 7.5 month olds' abilities to segment words with weak/strong stress patterns. In contrast with the results for strong/weak words, 7.5 month olds appeared to missegment weak/strong words. They demonstrated a tendency to treat strong syllables as markers of word onsets. In addition, when weak/strong words co-occurred with a particular following weak syllable (e.g., ''guitar is''), 7.5 month olds appeared to misperceive these as strong/weak words (e.g., ''taris''). The studies in Part III examined the abilities of 10.5 month olds to segment weak/strong words from fluent speech. These older infants were able to segment weak/strong words correctly from the various contexts in which they appeared. Overall, the findings suggest that English learners may rely heavily on stress cues when they begin to segment words from fluent speech. However, within a few months time, infants learn to integrate multiple sources of information about the likely boundaries of words in fluent speech.

This work was supported by Research Grant 15705 from NICHD and a Senior Scientist Award 01490 from NIMH to P.W.J. We thank Michele Shady for her assistance in recording the stimulus materials and Ann Marie Jusczyk, Amy Gambon-Dennis, Aileen Warden, and Debra Dombrowski for their help in recruiting and testing infants. In addition, Ann Marie Jusczyk, Theresa Allocco, and Jan Charles-Luce also provided valuable help for the acoustic analyses that we conducted. Finally, we are grateful to Ann Marie Jusczyk, Sven Mattys, James McQueen, and two anonymous reviewers for helpful comments that they made on earlier versions of the present paper.

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0010-0285/99 $30.00

A crucial step in mastering any language is to learn its words. However, because language learners most often hear words not individually, but in the context of other words in a sentence (van de Weijer, 1998; Woodward & Aslin, 1990), acquiring a vocabulary in the native language depends on some ability to segment words from fluent speech. Although the field of infant speech perception research is about 30 years old, it is only within the last 5 years that the speech segmentation abilities of language learners have been seriously investigated. Research in this area has burgeoned because evidence from a number of investigations indicated that, during the second half of the first year, infants have begun to learn about the sound organization of their native language (Aslin, Jusczyk, & Pisoni, 1997). For instance, although infants' ability to discriminate native language phonetic contrasts remains high, their ability to discriminate certain nonnative contrasts begins to decline during this period (Best, Lafleur, & McRoberts, 1995; Werker & Lalonde, 1988; Werker & Tees, 1984). Furthermore, infants at this age have been shown to be sensitive to features of native language sound structure that are potentially useful in word segmentation. For example, between 6 and 9 months of age, infants develop sensitivity to phonotactic properties of native language words (Friederici & Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993b; Jusczyk, Luce, & Charles Luce, 1994). In addition, sensitivity to the predominant stress patterns of native language words has been found to develop during this period (Jusczyk, Cutler, & Redanz, 1993a; Turk, Jusczyk, & Gerken, 1995). The fact that infants respond to these potential markers of word boundaries in the input has generated much interest in the word segmentation abilities of infants at this age.

Word segmentation research has also been furthered by the development of suitable testing procedures to explore infants' abilities. Most of the early procedures used in testing infants permitted only the presentation of utterances of two or three syllables. However, the development of new methods, which allow for the presentation of longer utterances, has enabled researchers to begin to investigate the word segmentation abilities of infants. Jusczyk and Aslin (1995) successfully adapted one such method, the Headturn Preference Procedure (HPP), to explore whether English-learning 7.5 month olds can segment monosyllabic words from fluent speech. They familiarized infants with a pair of target words, such as ''cup'' and ''dog'' (or ''feet'' and ''bike''). Then, they measured infants' listening times to four different six-sentence passages. In two of these passages, one of the familiarized target words appeared in every sentence. The other two passages were similarly structured but included the target words not heard during familiarization (i.e., ''feet'' and ''bike'' for infants who had been familiarized with ''cup'' and ''dog''). Jusczyk and Aslin predicted that infants would listen significantly longer to the passages containing the familiarized target words than to the ones with the unfamiliar targets. In fact, 7.5 month olds, but not 6 month olds, did listen significantly longer to the passages with the familiarized targets, suggesting that they were able to recognize the targets in sentential contexts.

As a check on whether the infants were actually responding to the entire target word in the sentential context or to a salient feature of it such as the vowel, Jusczyk and Aslin familiarized another group of 7.5 month olds with nonsense target words, such as ''tup'' and ''bawg'' and then tested them on the same four passages. In contrast to the earlier results, these infants did not listen longer to the passages containing the words that were similar to the targets (i.e., the ''cup'' and ''dog'' passages in this example). Thus, the 7.5 month olds in the first experiment appeared to be responding to the whole word rather than just to its vowel. This finding received additional confirmation in a subsequent study by Tincoff and Jusczyk (1996), who found that 7.5 month olds who were familiarized with items such as ''cut'' and ''dawb'' also did not listen longer to passages containing ''cup'' and ''dog.'' Thus, infants seem to be encoding information about both the initial and final consonants of the target items. Finally, Jusczyk and Aslin investigated whether infants familiarized with two of the passages would subsequently listen longer to repetitions of the target words from those passages than to repetitions of two unfamiliar target words. Infants did listen significantly longer to the target words that had appeared in the passages. Consequently, even when their initial exposure was to the targets in fluent speech, the 7.5 month olds gave evidence of segmenting the words from these contexts.

Jusczyk and Aslin's study demonstrated that English-learning 7.5 month olds have some capacity to segment monosyllabic words from fluent speech. However, their study leaves open the means by which infants segment words from fluent speech contexts. Words in sentences are not separated from one another by clear pauses. Instead, speakers are more apt to run words together, making it difficult to tell where one word ends and another begins. Indeed, the tendency of speakers to run words together has proven to be a formidable hurdle for the recognition of speech by machines (Bernstein & Franco, 1996; Klatt, 1979; Marcus, 1984; Reddy, 1976; Waibel, 1986). Because they cannot count on pauses between words, listeners must rely on other information in the speech signal to indicate how word boundaries are marked. Learning which features mark word boundaries in a particular language seems to involve discovering the way that sounds are typically ordered—phonetically and prosodically—within words in the language. These patterns differ from one language to another. Consequently, learners must discover the sound properties that are the most useful cues to word boundaries in their native language. A number of potential cues to word boundaries have been suggested for English; among these are (1) distributional or statistical cues; (2) context-sensitive allophones; (3) phonotactic constraints; and (4) prosodic cues. The focus of the present paper is on the last of these cues. However, before discussing the potential role of prosodic cues, we briefly consider the other kinds of cues and how they may be used by language learners.

It has been suggested that learners might be able to take advantage of certain distributional properties (Brent & Cartwright, 1996; Suomi, 1993) or statistical regularities (Saffran, Aslin, & Newport, 1996a; Saffran, Newport, & Aslin, 1996b) regarding word boundaries in the input. For example, an infant who learns some words spoken as isolated utterances might match a stored representation of these sound patterns to fluent speech, breaking the input into a known and one or more unknown strings. These unknown strings might be stored as unanalyzed units. So, if ''cat'' is known, it can be matched in the utterance ''See the cat,'' with the result that ''see the'' would be an unanalyzed unit. Eventually, learners will hear ''see'' and ''the'' in other distributional contexts, and the contrast between these and the stored sequence of ''see the'' lead to the decomposition of the unit into the lexical items ''see'' and ''the.'' Although this approach has not yet been tested directly with infants, Brent and Cartwright (1996) describe a successful computer simulation model for word segmentation based on such cues.

Similarly, knowing something about the likelihood that one syllable follows another could also be useful to learners in discovering word boundaries. For example, consider the utterance ''pretty baby.'' Because ''pretty'' and ''baby'' can occur in combination with many other words, the likelihood of the second syllable following the first and the fourth syllable following the third is high relative to that of the third syllable following the second. Saffran et al. (1996a) examined whether 8 month olds might be able to take advantage of these sorts of statistical regularities to learn about word boundaries in a nonsense language. They exposed 8 month olds to 2 min of a continuous stream of speech, consisting of four trisyllabic nonsense words, repeating in a random order. The only cues to word boundaries in this continuous stream were the transitional probabilities between syllable pairs. Specifically, transitional probabilities were higher for syllable pairs within words than between words. During the test phase, the infants were found to distinguish trisyllables that conformed to words during the familiarization phase from trisyllables that spanned word boundaries. Hence, the infants demonstrated some ability to use statistical regularities to segment words from continuous speech.

Attention to the particular contexts in which variants (or allophones) of the same phoneme appear can also provide clues to the location of word boundaries (Bolinger & Gerstman, 1957; Church, 1987a; Gow & Gordon, 1995; Hockett, 1955; Lehiste, 1960; Umeda & Coker, 1974). Church (1987a) notes that the allophone of /t/ that begins words in English, such as ''top'' (i.e., [t^h]) is not found in other positions in English words, such as the /t/s in ''stop'' or ''hot.'' A listener sensitive to the distribution of these allophones could use this information in deciding whether a word boundary has occurred. Moreover, English-learning infants as young as 2 months old can discriminate the kinds of allophonic differences that could indicate the presence of a word boundary in ''night rates'' and the absence of a word boundary in ''nitrates'' (Hohne & Jusczyk, 1994). There is also evidence that English-learning 10.5 month olds, but not 9 month olds, can draw on these allophonic differences in segmenting words from fluent speech contexts (Jusczyk, Hohne, & Bauman, in press). So, toward the end of the first year, attention to allophonic cues does appear to play some role in word segmentation by English-learning infants.

Phonotactic constraints (restrictions on the permissible sequences of phonetic segments in words) have also been suggested as a potential source of information about word boundaries (Brent, 1997; Brent & Cartwright, 1996; Cairns, Shillcock, Chater, & Levy, 1997). For example, knowledge that English does not allow sequences of consonants such as ''db'' or ''kt'' at the beginnings of words could be used to infer a potential word boundary between these two consonants. Based on the success of their neural net model trained on a corpus of conversational English, Cairns et al. concluded that sensitivity to the distribution of the phonotactic patterns in the input could suffice to identify word boundaries for language learners. Similarly, the computer simulation model of Brent and Cartwright (1996), INCDROP, showed significant gains in accuracy in locating word boundaries when phonotactic cues were available. There is also some suggestive evidence from recent studies with infants that indicates they are sensitive to phonotactic cues to word boundaries. Myers, Jusczyk, Kemler Nelson, Charles-Luce, Woodward, and Hirsh-Pasek (1996) noted that the presence of phonotactic cues may have helped English-learning 10.5 month olds detect pauses that interrupted words with weak/strong stress patterns. Friederici and Wessels (1993) found that Dutch-learning 9 month olds distinguished between permissible and impermissible phonotactic sequences in the onsets and offsets of syllables. More recently, Mattys, Jusczyk, Luce, and Morgan (1999) found that 9-month-old English learners are sensitive to how phonotactic sequences typically align with word boundaries.

Knowledge of native language prosodic patterns—the focus of the present study—has also been suggested as a potential cue to word boundaries in fluent speech (Cutler, 1994; Cutler & Clifton, 1985; Cutler & Norris, 1988; Grosjean & Gee, 1987). In their analysis of a large corpus of spoken English, Cutler and Carter (1987) found that about 90% of lexical (i.e., content) words began with strong syllables (i.e., syllables containing a full vowel). Moreover, evidence from a variety of tasks using fluent speech indicates that English-speaking adults are apt to identify word onsets with the occurrence of strong syllables (Cutler & Butterfield, 1992; Cutler & Norris, 1988; McQueen, Norris, & Cutler, 1994). On the basis of these findings, Cutler and her colleagues have suggested that English listeners follow a Metrical Segmentation Strategy (MSS) whereby, as a first pass at parsing words, strong syllables are indicators of onsets of new words in the speech stream (Cutler, 1990; Cutler & Butterfield, 1992; Cutler, McQueen, Baayen, & Drexler, 1994; Cutler & Norris, 1988). However, in order for language learners to use information about strong syllables as markers of word onsets, they first must show sensitivity to this property of English lexical words. It was in order to determine when infants display such sensitivity that Jusczyk, Cutler, and Redanz (1993a) examined how English-learning infants respond to bisyllabic words with strong/weak vs. weak/strong stress patterns. As noted earlier, their investigation indicated that 9 month olds, but not 6 month olds, listened significantly longer to words with strong/weak than with weak/strong stress patterns. Hence, the evidence suggests that sensitivity to the predominant stress pattern of English words develops between 6 and 9 months of age.

Several subsequent investigations have provided evidence that sensitivity to the location of strong syllables affects the way that English learners group information in strings of syllables. Morgan (1994) used a conditioned headturn procedure with 8 month olds and found that such rhythmic cues were effective in grouping syllables from a three-syllable utterance into smaller units. In addition, a second measure Morgan used indicated that 8 month olds were less likely to detect a target noise when it occurred between syllables that were rhythmically clustered by reference to the location of strong syllables. In a later investigation, Morgan (1996) found that 9 month olds perceived novel bisyllables as cohesive only when they had a trochaic (i.e., strong/weak) stress pattern. More recently, Echols, Crowhurst, and Childers (1997) reported that English-learning 9 month olds who were trained with three syllable sequences with weak/strong/weak stress patterns were significantly better at recognizing strong/weak sequences from these longer patterns than they were at recognizing weak/strong sequences. A similar result was obtained in a follow-up experiment by Echols et al. when the infants were familiarized with four-syllable sequences.

Hence, English-learning infants show some tendency to use information about the locus of strong syllables in grouping and extracting syllable sequences from longer strings of speech. Still, the infants tested in the studies just discussed were dealing with sequences that were only three or four syllables long. The present investigation was undertaken to determine whether, when faced with the complexities of a continually changing stream of fluent speech, English learners give evidence of relying on a prosodically based strategy, such as MSS, in segmenting words. To evaluate this possibility, we conducted a three-part study, using the version of the Headturn Preference Paradigm developed by Jusczyk and Aslin, to investigate the abilities of English learners to detect words with either strong/weak or weak/strong stress patterns in fluent speech. If English learners begin to segment words by identifying word onsets with the location of strong syllables, as predicted by MSS, they should be more successful in segmenting words with strong/weak than with weak/strong stress patterns. In Part I of our investigation, we conducted a series of studies exploring 7.5 month olds' abilities to segment strong/weak words from fluent speech. In Part II, the focus of the investigation was on 7.5 month olds' abilities to segment weak/strong words. In Part III, we investigated the segmentation of weak/strong words in older infants, 10.5 month olds.

PART I: HOW 7.5 MONTH OLDS RESPOND TO STRONG/WEAK WORDS IN FLUENT SPEECH

If English learners have a tendency to identify the onset of words with the occurrence of strong syllables in the speech stream, then they would be likely to correctly locate the onset of a strong/weak word, such as ''falter.'' In contrast, weak/strong words, such as ''disrupt,'' might be problematic because a tendency to infer a word boundary before a strong syllable would lead the learner to place ''dis'' and ''rupt'' in different words. In this first series of studies, we investigated the ability of English-learning 7.5 month olds to segment words with strong/weak patterns. We tested 7.5 month olds because previous work by Jusczyk and Aslin (1995) indicated that infants at this age have some ability to detect familiarized target words in fluent speech contexts. In examining the ability of 7.5 month olds to segment strong/weak words, we also investigated the nature of the information that they extracted about such words. It has long been held in the language acquisition literature that learners might attend more closely to stressed syllables and ignore unstressed (or weak) syllables (Brown, 1958; Echols & Newport, 1992; Gleitman & Wanner, 1982). Thus, we examined whether infants attend to entire strong/weak words or only to the strong syllables of these words.

Experiment 1

In their investigation, Jusczyk and Aslin (1995) demonstrated that 7.5 month olds who were familiarized with monosyllabic target words subsequently listened significantly longer to passages with these words than to ones without them. The monosyllabic targets in their study were lexical words and included full vowels (i.e., ''cup,'' ''dog,'' ''feet,'' and ''bike''). However, it is possible that infants at this age might segment monosyllabic words without necessarily being able to segment longer words, such as bisyllables, from fluent speech. Thus, the first step in the present investigation was to determine whether we could replicate Jusczyk and Aslin's results when we used bisyllabic words with strong/weak stress patterns. The target words selected for the present study were the words ''kingdom,'' ''hamlet,'' ''doctor,'' and ''candle.'' One factor in choosing these particular items was that the strong syllable in each one corresponds to a lexical word in English. This consideration was important for some of the succeeding experiments in this series.

As in the earlier Jusczyk and Aslin study, each infant was familiarized with a pair of target words (either ''kingdom'' and ''hamlet'' or ''doctor'' and ''candle''). The items in the familiarization period consisted of different tokens of the target words that had been produced by a single talker as isolated repetitions of the same word. Once the infants completed the familiarization period, they were tested on four six-sentence passages, two of which contained the familiarized targets in every sentence and two of which contained the same number of unfamiliar targets. In accord with Jusczyk and Aslin's findings, we predicted that if the 7.5 month olds detected the occurrence of the familiarized bisyllabic targets in the passages, they would listen significantly longer to these passages than to the ones with the unfamiliar bisyllabic targets.

Method

Participants. The participants were 24 American infants (13 males, 11 females). The infants in this experiment, and in all succeeding experiments in this study, were American infants from monolingual English-speaking homes. The infants all were recruited from Buffalo and its surrounding suburbs. The ethnic breakdown across the series of experiments was approximately 85% Caucasian, 12% African–American, 3% Other (Native American, Hispanic, and mixed race). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 4 days (range: 30 weeks, 4 days, to 37 weeks, 1 day). To obtain the 24 infants for this study, it was necessary to test 34. Infants were excluded for the following reasons: crying (6) and looking times averaging less than 3 s to the passages (4).

Stimuli. A female talker, who was a native speaker of American English from western New York, recorded four different six-sentence passages (see Table 1). She was encouraged to read the passages in a lively voice, as if reading to a small child. The recordings were made in a sound-attenuated room with a Shure microphone. The critical passages were digitized on a VAXStation Model 3176 computer at a sampling rate of 10 kHz via a 12-bit analog-to-digital converter. The average duration of the passages was 20.55 s (ranging from 19.87 s for the ''doctor'' passage to 21.28 s for the ''hamlet'' passage).

Acoustic analyses on the target words in the sentences indicated that the average duration of the first (stressed) syllable (320 ms) was significantly longer than that of the second (unstressed) syllable (191 ms) ($F(1, 20) = 429.94$, $p < .0001$). In addition, the average pitch peaks of the first syllables of these target words (278 Hz) were significantly higher than those of the second syllables (220 Hz) ($F(1, 20) = 7.05$, $p < .02$). With respect to the indivi-

TABLE 1
Passages with Strong/Weak Target Words

Kingdom passage

Your kingdom is in a faraway place. The prince used to sail to that kingdom when he came home from school. One day he saw a ghost in this old kingdom. The kingdom started to worry him. So he went to another kingdom. Now in the big kingdom he is happy.

Hamlet passage

Your hamlet lies just over the hill. Far away from here near the sea is an old hamlet. People from the hamlet like to fish. Another hamlet is in the country. People from that hamlet really like to farm. They grow so much that theirs is a very big hamlet.

Doctor passage

The doctor saw you the other day. He's much younger than the old doctor. I think your doctor is very nice. He showed another doctor your pretty picture. That doctor thought you grew a lot. Maybe someday you'll be a big doctor.

Candle passage

The candle in the kitchen was almost melted. So Annie bought another candle at the stationery store. She came home and put away the old candle. Fran gave that candle to you later. Then she made a place for the new big candle. Your candle is very pretty and smells nice too.

dual target words, the average duration of the first and second syllables were 301 and 215 ms (kingdom), 354 and 200 ms (hamlet), 291 and 204 ms (doctor), and 333 and 143 ms (candle). The average pitch peaks of the first and second syllables were 345 and 226 Hz (kingdom), 248 and 225 Hz (hamlet), 268 and 224 Hz (doctor), and 252 and 215 Hz (candle). Thus, the strong syllables of the targets were longer and had higher peaks than did the weak syllables.

Once it was determined that the passages were acceptable for use in the experiment, the talker was asked to record versions of the isolated words to be used during the familiarization phase of the experiment. For each target word, the talker was asked to repeat the item with some variation 15 times in a row, in a lively voice, and as if naming the object for an infant. These lists were then digitized on the computer in the same way as the sentences. The average duration of the lists was 21.78 s (ranging from 21.14 s for the ‘‘hamlet’’ list to 22.78 s for the ‘‘kingdom’’ list).

The acoustic analyses for the isolated target words indicated that there was no overall difference in duration for the first (368 ms) and second syllables (375 ms) ($F(1, 56) < 1.00$). Given that these words were produced in isolation, this is not surprising, because word and utterance final syllables are lengthened in these contexts (Klatt, 1976). However, the pitch peaks of the first syllables (500 Hz) were, once again, significantly higher than those of the second syllables (311 Hz) ($F(1, 56) = 38.11$, $p < .0001$). Thus, the main correlate of syllable stress for these items was the higher pitch peak of the first (stressed) syllables relative to the second (unstressed) syllables. For the individual target words, the average durations of the first and second syllables were 308 and 390 ms (kingdom), 403 and 256 ms (hamlet), 399 and 462 ms (doctor), and 362 and 390 ms (candle). The average pitch peaks of the first and second syllables were 519 and 331 Hz (kingdom), 509 and 265 Hz (hamlet), 446 and 329 Hz (doctor), and 528 and 319 Hz (candle).

Digitized versions of the passages and the lists were transferred to a PDP 11/73 computer for playback during the experiment.

Design. Half of the infants heard the words ‘‘kingdom’’ and ‘‘hamlet’’ during the familiarization phase, and the other half heard the words ‘‘doctor’’ and ‘‘candle.’’ During the test phase, all the infants heard four blocks of the same four passages. Each block contained a different random ordering of the passages corresponding to ‘‘kingdom,’’ ‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle.’’

Apparatus. A PDP 11/73 controlled the presentation of the stimuli and recorded the observers’ coding of the infants’ headturn responses. The audio output for the experiment was generated from the digitized waveforms of the samples. A 12-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 one of two 7 -in. Advent loudspeakers mounted on the side walls of the testing booth.

Procedure. The experiment was conducted in a three-sided test booth constructed out of 4 × 6 ft pegboard panels on three sides and open at the back. An observer looked through one of the existing pegboard holes in the front panel to monitor the infant’s head turns. Except for a small section for viewing the infant, the remainder of the pegboard panels were backed with white cardboard to guard against the possibility that the infant might respond to movements behind the panel. The test booth had a red light and a loudspeaker mounted at eye level on each of the side panels and a green light mounted on the center panel. Directly below the center light a 5-cm hole accommodated the lens of a video camera used to record each test session. A white curtain suspended around the top of the booth shielded the infant’s view of the rest of the room. A computer terminal and response box were located behind the center panel, out of view of the infant. The response box, which was connected to the computer, was equipped with a series of buttons that started and stopped the flashing center and side lights, recorded the direction and duration of head turns, and terminated a trial when the infant looked away for more than 2 s. Information about the direction and duration of head turns and the overall duration of each trial was stored in a data file on the computer. Computer software was responsible for the selection and randomization of the stimuli and for the termination of the test trials. The average listening times for the test items were calculated by the computer following the completion of each session.

A version of the Headturn Preference Procedure was used (for an extensive discussion concerning the reliability of this procedure, see Jusczyk, 1998; Kemler Nelson et al., 1995; Polka, Jusczyk, & Rvachew, 1995). Each infant was held on a caregiver's lap. The caregiver was seated in a chair in the center of the test booth. Each trial was begun by blinking the green light on the center panel until the infant had oriented in that direction. Then, the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a headturn of at least 30° in the direction of the loudspeaker, the stimulus for that trial began to play and continued until its completion or until the infant failed to maintain the 30° headturn for 2 consecutives (e.g., if the infant turned back to the center or the other side or looked at the mother, the floor, or the ceiling). If the infant turned briefly away from the target by 30° in any direction, but for less than 2 s, and then looked back again, the time spent looking away was not included in the orientation time. Thus, the maximum orientation time for a given trial was the duration of the entire sample. The flashing red light remained on for the entire duration of the trial.

Each experimental session began with a familiarization phase in which infants heard repetitions of two of the target items on alternating trials until they accumulated 30 s of listening time to each one. If the infants achieved the familiarization criterion for one item, but not for the other, the trials continued to alternate until the criterion was achieved for both. The location of the loudspeaker from which the words were emitted was varied from trial to trial, with a different random order used for each infant.

The test phase began immediately after the familiarization criterion was attained. The stimuli for the test phase consisted of the four six-sentence passages. The order of each of the sentences within a passage was fixed and the same for all infants. Each trial always began with the first of the six sentences in the passage. The test trials were blocked in groups of four so that each passage occurred once per block. The order of the passages within a block was randomized. Each infant was tested on four blocks, for a total of 16 test trials.

An observer hidden behind the center panel looked through the peephole and recorded the direction and duration of the infant's head turns using a response box. The observer was not informed as to which items served as familiarization words for a given infant. The loudness levels for the samples were set by a second assistant, who was not involved in the observations, at 72 $\pm$ 2 dB (C) SPL. Both the observer and the infant's caregiver wore foam earplugs and listened to masking music over tight-fitting closed headphones (SONY MDR-V600). The masker consisted of loud instrumental music, which had been recorded with few silent periods. Caregivers and observers reported that with this masker they were unaware of either the location or the nature of the stimulus on the trial. Reliability checks between the live observer and observers of the videotapes of each session are high, with correlations ranging from .92 to .96 (Kemler Nelson et al., 1995).

Results and Discussion

In experiments using this procedure (Jusczyk & Aslin, 1995; Jusczyk et al., in press), listening times tend to decline across blocks. However, no consistent patterns have emerged in block-by-block analyses of data. The same held true for the present experiment and the succeeding experiments in the current investigation. Hence, our analyses in all experiments are focused on the mean listening times to the four different passages, calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Eighteen of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were

7.92 s ($SD = 2.77$ s) for the passages with the familiarized words and 6.80 s ($SD = 2.71$ s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was significant ($t(23) = 2.67$, $p < .02$). Therefore, the results indicate that 7.5 month olds familiarized with isolated versions of strong/weak target words were able to detect these same words when they occurred in the test passages.

The present findings replicate and extend the earlier ones of Jusczyk and Aslin (1995) by demonstrating that 7.5 month olds can segment bisyllabic words with strong/weak stress patterns from fluent speech contexts. Evidence for segmentation occurred when infants were familiarized first with isolated instances of the target words. This situation is similar to the one that holds for adult listeners who recognize words that they already know in fluent speech contexts. Recognizing words in such contexts does seem to depend on some ability to segment the signal into the correct words in order to achieve a match between a known lexical item and its match in a portion of an utterance. However, as Jusczyk and Aslin (1995) noted, language learners receive only a relatively small proportion of words in isolated contexts. Many words that infants learn are more likely to occur first in sentential contexts. Learning to segment words first from sentential contexts may be considerably more difficult, not only because there is information pertaining to other words in these utterances, but also because the onsets and offsets of words are not always clearly marked by acoustic discontinuities in the speech signal (Cole, 1980; Klatt, 1979). For this reason, Jusczyk and Aslin (1995) explored the robustness of 7.5 month olds' word segmentation abilities by including an experiment in which familiarization to the target words occurred in the context of fluent speech passages, and the test phase consisted of repetitions of target words produced in isolation. The results were similar to the earlier experiment; namely, the infants listened significantly longer to the isolated words that had previously occurred as target words in the familiarization passages. This suggests that the infants were able to extract the target words from the sentential contexts during the familiarization period. Thus, even when the words first occurred in sentential contexts, the infants displayed some subsequent recognition of these when they heard them as isolated words during the test period. Would 7.5 month olds show the same capabilities with bisyllabic words, or would the greater length and complexity of these words affect the ability to segment these items from fluent speech contexts? To investigate this issue, we conducted another experiment in which we familiarized infants with the bisyllabic target words in the passages and then tested them on repetitions of isolated words.

Experiment 2

Method

Participants. The participants were 24 American infants (17 males, 7 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 3 days (range: 31 weeks, 1 day, to 34 weeks, 5 days). To obtain the 24 infants for this study, it was necessary to test

32. Infants were excluded for the following reasons: crying (5), looking times averaging less than 3 s to the passages (1), failure to look at the flashing lights (1), and restlessness (1).

Stimuli. The same repeated word tokens and fluent speech passages were used as in Experiment 1.

Design. Half of the infants were familiarized with the ''kingdom'' and ''hamlet'' passages and the other half were familiarized with the ''doctor'' and ''candle'' passages. During the test phase, all the infants heard three blocks of the same four lists of repeated, isolated tokens of the bisyllabic words. Each block contained a different random ordering of the lists of the words ''kingdom,'' ''hamlet,'' ''doctor,'' and ''candle.''

Apparatus. The same equipment was used as that in Experiment 1.

Procedure. The procedure was identical to the one used in Experiment 4 of Jusczyk and Aslin (1995). The main change from the previous experiment involved reversing the roles of the passages and isolated word lists. During the familiarization phase, infants were exposed to two passages on alternating trials. The familiarization period lasted until an infant had listened to each passage for about 45 s (long enough to have heard each target word about 12 times). During the test phase, a given trial involved the presentation of a list consisting of repetitions of the different tokens of one of the four target words (e.g., ''doctor,'' ''doctor,''. . ., ''doctor''). The order of the presentation of the target words was randomized within a block of four trials. Each infant heard three different blocks of trials for a total of 12 test trials. Given the longer familiarization period, the reduction in the length of the test period was necessary to prevent boredom and fussiness by the infants toward the end of the test period.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Twenty of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 9.59 s (SD = 2.55 s) for the lists with the familiarized words and 7.55 s (SD = 2.84 s) for the lists with the unfamiliar words. A paired t test indicated that this difference in average listening times was significant ($t(23) = 4.16$, $p < .0005$). Thus, the present findings indicate that 7.5 month olds are able to recognize at least some bisyllabic words in isolation that they have previously heard only in sentential contexts. Evidently, the greater length and complexity of these items relative to monosyllabic words did not hinder infants from detecting them in fluent speech contexts.

The listening time difference between the familiar and unfamiliar targets was actually larger in Experiment 2 (2.04 s) than in Experiment 1 (1.12 s), despite the fact that in the former, infants' initial exposure to the target words occurred in the context of other words in the passages. Thus, contrary to the suggestion mentioned in the discussion of Experiment 1, infants did not appear to have more difficulty in segmenting words when they first encountered them in the passages. To better assess whether there were any significant differences in responding in these two experiments, we subjected the data from Experiments 1 and 2 to an ANOVA of 2 (Experiment) $\times$ 2 (Word Familiarity) mixed design. The main effect of Experiment was marginally significant ($F(1, 46) < 2.87$, $p < .10$), reflecting the fact that, during the test phase, the overall listening times tend to be longer when infants are listening to isolated words. This difference is likely a consequence of the fact that listening times decline across blocks of trials and there are fewer blocks of trials when the test items are the isolated words. As expected, the main effect of Word Familiarity was significant ($F(1, 46) = 23.96$, $p < .0001$). However, and most importantly, the interaction between these two factors was not significant ($F(1, 46) = 2.08$, $p < .20$), indicating that infants in both experiments showed the same tendency to listen longer to the familiarized targets during the test phase. In general, the pattern that we have observed for these first two experiments holds for other experiments in the current study and in the earlier Jusczyk and Aslin (1995). That is, the pattern of results obtained from procedures in which infants are familiarized with isolated words and tested on passages tend to mirror those when they are familiarized with passages and then tested on isolated words.

Although the results of these first two experiments indicate that infants have some ability to segment bisyllabic words from speech, they do not indicate whether infants are actually responding to the whole words or to a salient portion of them, such as the strong syllables. As noted earlier, it has been suggested that because of their greater acoustic salience, strong syllables may draw the attention of language learners (Brown, 1958; Echols & Newport, 1992; Gleitman & Wanner, 1982). Hence, it is conceivable that infants in the first two experiments were not responding to ‘‘kingdom’’ and ‘‘hamlet,’’ but rather to ‘‘king’’ and ‘‘ham.’’ One way to investigate this possibility is to examine whether infants who are familiarized with passages containing only the strong syllables of these words might subsequently listen longer to the whole words that include these strong syllables. The next four experiments were conducted to explore this issue.

Experiment 3

For an infant learning to segment speech, the rate at which speech sounds can be transmitted may pose difficulties in recognizing all of the information in the signal. For this reason, and also because of their presumed memory limitations, infants might be prone to attend to only the most salient syllables that are present in utterances. Strong syllables, which tend to be louder and longer than weak syllables, may be the ones in fluent speech that stand out for infants. Infants listening to a passage containing the word ‘‘kingdom’’ may attend only to ‘‘king.’’ If so, then infants who are familiarized with a passage containing the word ‘‘king’’ (as opposed to ‘‘kingdom’’) should respond in the same way as infants in Experiment 2. That is, they should listen significantly longer to the lists with isolated bisyllabic words that include strong syllables matching those heard in the passages during the familiarization period. To investigate this possibility, we constructed four new passages; one each for the words ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can.’’ Infants were familiarized with two of these passages and then tested on the four lists with the words ‘‘kingdom,’’ ‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle.’’ A finding that infants listen significantly longer to the lists with the words that included the syllables heard during familiarization would be consistent with the view that they respond primarily to the strong syllables of the bisyllabic words.

Method

Participants. The participants were 24 American infants (12 males, 12 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 2 days (range: 30 weeks, 2 days, to 35 weeks, 1 day). To obtain the 24 infants for this study, it was necessary to test 25. One infant was excluded because of experimenter error.

Stimuli. The same female talker from western New York recorded four new test passages for the words ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can.’’ The passages are shown in Table 2. The passages were recorded in exactly the same manner and under the same recording conditions as those for the original fluent speech passages. The average duration of the passages was 21.60 s (ranging from 21.22 s for the ‘‘can’’ passage to 22.00 s for the ‘‘ham’’passage). Acoustic analyses of the targets in the passages indicated that the average duration and average pitch peak of the targets were the following: 400 ms and 228 Hz (king), 428 ms and 240 Hz (ham), 369 ms and 265 Hz (dock), and 402 ms and 260 Hz (can). In addition to the new passages, the same lists of the bisyllabic words produced in isolation were used as in the previous two experiments.

Design. The design was essentially the same as that for Experiment 2, with the four new passages substituted for the ones used in the earlier experiment. Infants were familiarized with either the ‘‘king’’ and ‘‘ham’’ or the ‘‘dock’’ and ‘‘can’’ passages. During the test phase, all the infants heard three blocks of the same four lists of repeated, isolated tokens of the bisyllabic words. Each block contained a different random ordering of the lists of the words ‘‘kingdom,’’‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle.’’

TABLE 2
Passages with Strong Syllable Target Words

King passage
Your king groans a lot. The nice, big king likes to laugh. The son of the old king will soon visit them. The prince will tell a joke to the king. Then he will tell it to the new king. That king will smile, too.

Ham passage
The ham for dinner is almost ready. Dad brought home a new ham. Everyone liked that ham for Thanksgiving dinner. Your ham will taste very good. Mom almost baked an old ham that she had last Christmas. It was a spicy, baked ham.

Dock passage
The dock by the lake had sailboats. Motor boats stay at the old dock. That dock gets very busy. Fishing from the dock looks like fun. People at your dock like to swim, too. A family brought their boat to the new dock.

Can passage
The can with the apple sauce is on the shelf. You can holds alphabet soup. Beans from the new can will be good, too. We’ll dust off the old can. It is by the big can hiding in the back. It will be hard to reach that can.

Apparatus. The same equipment was used as that in Experiment 1.

Procedure. With the exception of the fact that new passages were used in the present experiment, the procedure was identical to that described for Experiment 2.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Eleven of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 9.94 s ($SD = 3.71$ s) for the lists with the familiarized words and 10.50 s ($SD = 3.40$ s) for the lists with the unfamiliar words. A paired t test indicated that this difference in average listening times was not significant ($t(23) = 1.03$, $p < .35$; 95% CI: $-0.56 < 0.56 < 1.68$).[1] Thus, the 7.5 month olds did not show any significant tendency to listen longer to the words in the test period (e.g., ‘‘hamlet’’) that included the strong syllables that they had heard in the passages (e.g., ‘‘. . . ham . . .’’) during the familiarization period. The findings suggest that the infants were not simply attending to the strong syllables of these words.

The pattern of results in the present experiment contrasts with that of Experiment 2, in which infants familiarized with strong/weak words in passages did listen significantly longer to the test words that had occurred in the passages. To verify that 7.5 month olds had responded differently in the two situations, we subjected the data from Experiments 2 and 3 to an ANOVA of a 2 (Experiment) × 2 (Word Familiarity) mixed design. There was a significant main effect of Word Familiarity ($F(1, 46) = 4.10$, $p < .05$), indicating that infants tended to listen longer to the familiarized words during the test period. There was also a marginally significant effect of Experiment ($F(1, 46) = 3.88$, $p < .10$) that was attributable to longer listening times in Experiment 3. Most importantly, the interaction between these two factors was highly significant ($F(1, 46) = 12.65$, $p < .001$), supporting the view that infants listened significantly longer to the targets in the test period after familiarization with strong/weak words.

In Experiment 3, infants were familiarized with monosyllabic words in passages and then tested on isolated versions of bisyllabic words which included the monosyllables heard during the familiarization period. However, it is possible that this test situation may not have been the best one for matching strong syllables in the familiarization period to ones in the test period. Although the infants may have extracted the strong syllables from the pas-

[1] Confidence intervals of 95% for the mean difference scores are provided for the crucial nonsignificant effects as an index of the power of the statistical test, as per Loftus and Masson (1994).

sages, the nature of the test stimuli, repetitions of isolated bisyllabic words, may have led infants to encode both syllables. If infants only encode the strong syllables of words in fluent speech context, then it may be more effective to familiarize them with bisyllabic words in passages and to determine whether they listen longer to the strong syllables of these words during the test period.

Experiment 4

In the present experiment, infants were familiarized with two passages containing either ‘‘kingdom’’ and ‘‘hamlet’’ or ‘‘doctor’’ and ‘‘candle.’’ During the test period, they were tested on repetitions of tokens of ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can’’ that were produced as isolated words. If in listening to fluent speech, infants attend only to strong syllables, then it was expected that they would listen significantly longer to the monosyllabic words that corresponded to the strong syllables of the bisyllabic words heard during familiarization. Thus, infants who had heard the ‘‘doctor’’ and ‘‘candle’’ passages were expected to listen significantly longer to ‘‘dock’’ and ‘‘can’’ than to ‘‘king’’ and ‘‘ham.’’

Method

Participants. The participants were 24 American infants (10 males, 14 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 1 day (range: 30 weeks, 5 days, to 35 weeks, 0 days). To obtain the 24 infants for this study, it was necessary to test 29. Infants were excluded for the following reasons: crying (2), failure to look at the flashing lights (2), and restlessness (1).

Stimuli. The same female talker from western New York recorded 15 tokens each of the words ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can.’’ The words were recorded in the same manner and under the same recording conditions as the isolated word tokens in Experiment 1. The average duration of the lists was 19.16 s (ranging from 18.74 s for the ‘‘ dock’’ list to 19.74 s for the ‘‘ham’’ list). Acoustic analyses of the isolated target words indicated that the average duration and average pitch peak for each of the words were the following: 574 ms and 479 Hz (king), 529 ms and 418 Hz (ham), 369 ms and 265 Hz (dock), and 567 ms and 548 Hz (can). In addition to the new word lists, the passages for ‘‘kingdom,’’ ‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle’’ from Experiment 1 were used in the present study.

Design. Half of the infants were familiarized with the ‘‘kingdom’’ and ‘‘hamlet’’ passages and the other half were familiarized with the ‘‘doctor’’ and ‘‘candle’’ passages. During the test phase, all the infants heard three blocks of the same four lists of repeated, isolated tokens of the monosyllabic words. Each block contained a different random ordering of the lists of the words ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can.’’

Apparatus. The same equipment was used as that in Experiment 1.

Procedure. With the exception of the fact that new lists of isolated words were used in the present experiment, the procedure was identical to that described for Experiment 2.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Fourteen of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 9.58 s ($SD = 3.25$ s) for the lists with the familiarized words and 8.58 s ($SD = 3.52$ s) for the lists with the unfamiliar words. Although the difference in listening times to the lists of familiarized and unfamiliar words was 1 s, a paired t test indicated that this difference was not significant ($t(23) = 1.63$, $p < .15$; 95% CI: $-0.27 < 1.00 < 2.27$).

Once again, the present results do not provide any significant evidence that English-learning 7.5 month olds attend only to the strong syllables of strong/weak bisyllabic words. However, the difference in listening times for the familiarized versus the unfamiliar words was in the right direction compared to that of the previous experiment. In addition, more infants had longer listening times to the familiarized words in this experiment (14) than in the previous one (11).

As noted in the discussion of Experiment 1, it may be harder for infants to segment words when their initial familiarization with the targets occurs in passages than in lists of isolated words. Thus, as a further check on whether English learners attend only to the strong syllables of words in fluent speech, we conducted the following experiment. Infants were familiarized with a pair of monosyllables produced as isolated words (e.g., ‘‘king’’ and ‘‘ham’’ or ‘‘dock’’ and ‘‘can’’) and then tested on passages containing ‘‘kingdom,’’ ‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle.’’ A finding that infants listen significantly longer to the passages with the strong/weak words whose strong syllables correspond to the ones heard during familiarization would be an indication that they do attend primarily to strong syllables in fluent speech.

Experiment 5

Method

Participants. The participants were 24 American infants (15 males, 9 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 6 days (range: 31 weeks, 0 days, to 35 weeks, 5 days). To obtain the 24 infants for this study, it was necessary to test 34. Infants were excluded for the following reasons: crying (2), looking times averaging less than 3 s to the passages (4), failure to look at the flashing lights (1), restlessness (1), parental interference with infants’ responding during test trials (1), and experimenter error (1).

Stimuli. The same stimuli were used as those in Experiment 4.

Design. During the familiarization period, on alternating trials, infants were exposed to repetitions of tokens of one of a pair of words produced in isolation. Half of the infants were familiarized with ‘‘king’’ and ‘‘ham’’ for 30 s to each word. The other half of the infants were familiarized with ‘‘dock’’ and ‘‘can.’’ During the test period, all the infants heard the four six-sentence test passages for the bisyllabic words (see Table 1). The passages were randomized in each block. Each infant heard four blocks of test trials.

Apparatus. The same equipment was used as that in the previous experiments.

Procedure. This was essentially the same as the one used in Experiment 1. The only difference was that during the familiarization period of the present experiment, the infants were exposed to a pair of monosyllabic words rather than to a pair of bisyllabic words.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Fourteen of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 7.75 s ($SD = 2.39$ s) for the passages with the familiarized words and 7.06 s ($SD = 2.37$ s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was not significant ($t(23) = 1.33$, $p < .20$; 95% CI: $-0.37 < 0.69 < 1.75$). Hence, the results were essentially the same as those of Experiment 4. Once again, there was no evidence that infants listened longer to the test items that included the syllables heard during the familiarization period.[2]

The pattern of results across Experiments 1–5 seems to indicate that English-learning 7.5 month olds can segment whole strong/weak bisyllabic words from fluent speech, rather than just a portion of these words, such as their strong syllables. Even though there was a partial match of information between the familiarization and test period in Experiments 3–5, this did not lead to significantly longer listening times for the test materials related to those heard during familiarization. One possible reason for this outcome is that the familiarization sets up expectations about the number of syllables present in the target words. Another possibility is that infants perceive some kind of acoustic mismatch between the monosyllabic items and the strong syllables of the strong/weak bisyllables. Given that the isolated familiarization tokens of Experiment 1 did not acoustically match the word tokens in the passages, this second explanation seemed implausible to us. However, it is possible that there were some subtle coarticulatory cues present in the bisyllabic utterances between the strong and weak syllables. Infants may have detected these and perceived a mismatch between the familiarization

[2] As part of this same study, we also tested 12 additional infants using a different familiarization set that included more than just the initial strong syllables of the strong/weak bisyllabic words. Specifically, these infants were familiarized with ‘‘canned’’ and ‘‘docked’’ and then tested on the same four test passages as the other 24 infants. Despite the slightly greater phonetic overlap between the familiarization words and the ones in the test passages, these infants did not show any greater tendency to listen to the passages with the words that included the familiarization words (i.e., the ‘‘candle’’ and ‘‘doctor’’ passages). The average listening times to these passages were 8.33 s ($SD = 2.67$ s) versus 8.49 s (2.64 s) for the passages with the unfamiliar targets. This difference was not significant ($t(11) = -0.29$, $p < .80$; 95% CI: $-0.35 < 0.2 < 0.75$).

targets and the strong syllables of the bisyllabic words in the passages. To check this possibility, we conducted an additional experiment in which the familiarization stimuli were strong syllables excised from the bisyllabic words that had been produced in isolation. Thus, the familiarization words contained the same coarticulatory cues that were present in the bisyllabic words in the passages. If the absence of such cues was a factor in Experiments 3–5, then when this information is present, the infants should listen significantly longer to the passages that correspond to the familiarized targets.

Experiment 6

Method

Participants. The participants were 24 American infants (16 males, 8 females). The infants were approximately 7.5 months old, with a mean age of 33 weeks, 4 days (range: 30 weeks, 6 days, to 34 weeks, 5 days). To obtain the 24 infants for this study, it was necessary to test 29. Infants were excluded for the following reasons: crying (1), looking times averaging less than 3 s to the passages (2), restlessness (1), and experimenter error (1).

Stimuli. The familiarization words were derived from the familiarization words used in Experiment 1. The strong syllables from the isolated versions ‘‘kingdom,’’ ‘‘hamlet,’’ ‘‘doctor,’’ and ‘‘candle’’ were excised by cutting the stimuli at the boundary between the first and second syllables, using a speech editing program developed by James Sawusch for the VAXStation. To avoid possible transients, the stimuli were cut at zero crossings. Adult listeners identified the resulting tokens as clear instances of ‘‘king,’’ ‘‘ham,’’ ‘‘dock,’’ and ‘‘can.’’ As in Experiment 1, there were 15 different tokens of each word, assembled into lists for each word type. The average duration of the familiarization lists was 17.63 s (ranging from 16.91 s for the ‘‘ham’’ list to 18.25 s for the ‘‘can’’ list). The test passages were the same as the ones used in Experiment 1.

Design. The design was identical to that of Experiment 5. Half of the infants were familiarized with ‘‘king’’ and ‘‘ham’’ for 30 s to each word. The other half of the infants were familiarized with ‘‘dock’’ and ‘‘can.’’ During the test period, all the infants heard the four six-sentence test passages for the bisyllabic words (see Table 1). The passages were randomized in each block. Each infant heard four blocks of test trials.

Apparatus and procedure. These were identical to the ones of Experiment 5.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Twelve of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 8.62 s ($SD = 3.35$ s) for the passages with the familiarized words and 7.74 s ($SD = 2.19$ s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was not significant ($t(23) = 1.40$, $p < .20$; 95% CI: $-0.42 < 0.88 < 2.18$). Hence, there was no evidence that infants listened longer to the test items that included the syllables heard during the familiarization period. Therefore, the presence of similar coarticulatory cues in the familiarized words and the words in the passages did not lead to significantly longer listening times to the passages related to the familiarized words. As in Experiments 3–5, an acoustic match between the strong syllables in the familiarization period and those in the test period did not lead to significantly longer listening times by English-learning 7.5 month olds.

Discussion of Part I

The overall pattern that emerges from these six experiments is that English-learning 7.5 month olds display some ability to segment strong/weak words from fluent speech contexts (Table 3). The familiarization items significantly affected infants' listening times to the items in the test period only when the familiarization and test items were matched in terms of the number of syllables that they contained (Experiments 1 and 2). Across four different test situations (Experiments 3–6), the infants did not show any significant tendency to respond to only the strong syllables of strong/weak words. This is not to imply that infants fail to detect any similarity between these strong syllables and the whole strong/weak words. In fact, there were nonsignificant tendencies to listen longer to the test items that were most similar to the ones heard during familiarization (e.g., to ''kingdom'' when familiarized with ''king''). However, the overall pattern of results suggests that infants were not just responding to a salient portion of the strong/weak words, such as their strong syllables. This pattern of findings is similar to the one observed by Jusczyk and Aslin (1995) with monosyllabic words. In that previous study, infants were found to respond to complete, as opposed to partial, matches between the familiarization and test words. The findings of Experiments 1 and 2 extend the previous ones by demonstrating that English-learning 7.5 month olds' abilities to segment words from fluent speech are not limited to monosyllabic words. Rather these infants are able to segment at least some kinds of bisyllabic words from fluent speech.

TABLE 3
Summary of Results of Experiments 1–6

Experiment	Familiarization stimuli	Test stimuli	Evidence of segmentation?
1	Isolated S/W words	Passages with S/W words	Yes
2	Passages with S/W words	Isolated S/W words	Yes
3	Strong syllable passages	Isolated S/W words	No
4	Passages with S/W words	Isolated strong syllables	No
5	Isolated strong syllables	Passages with S/W words	No
6	Strong syllables from S/W words	Passages with S/W words	No

The fact that English-learning 7.5 month olds show some ability to segment words that begin with strong syllables is certainly consistent with what is predicted if infants are using MSS in word segmentation (Cutler, 1990, 1994; Cutler & Norris, 1988; Jusczyk et al., 1993a). A tendency to associate onsets of words with the occurrence of strong syllables would help ensure that infants correctly locate the onsets of words beginning with strong syllables. Note that given previous findings (Jusczyk & Aslin, 1995; Tincoff & Jusczyk, 1996), it appears that infants are responding to information about the onsets of the strong syllables and not just to a salient perceptual feature of these such as the prominence of their vowels in the speech stream. Nevertheless, the findings to this point do not rule out bases for word segmentation other than that proposed in MSS. For example, it may be the case that infants are adept at segmenting many different kinds of words from fluent speech, including ones that begin with weak syllables. By comparison, note that an exclusive reliance on MSS would lead infants to missegment words that begin with weak syllables. For this reason, a better test of whether English-learning infants begin segmenting words by identifying possible word onsets with the occurrence of strong syllables is to examine how they fare with words that begin with weak syllables. The studies in Part II were designed to explore 7.5 month olds' abilities to segment weak/strong words from fluent speech.

PART II: HOW 7.5 MONTH OLDS RESPOND TO WEAK/STRONG WORDS IN FLUENT SPEECH

Although lexical words with initially stressed syllables may predominate in English conversational speech (Cairns et al., 1997; Cutler & Carter, 1987), many other stress patterns are represented in the language (Burzio, 1994). Even if language learners began by identifying word onsets with the occurrence of strong syllables, they would have to find some means of segmenting words that begin with weak syllables. To this point, the available evidence does not rule out the possibility that, from the outset, English-learning infants can segment words that do not have initially stressed syllables. For this reason, we decided to investigate whether English-learning 7.5 month olds can segment bisyllabic words with weak/strong stress patterns from fluent speech. A finding that English-learning 7.5 month olds do as well in segmenting weak/strong words as they do with strong/weak words would pose a serious problem for the view that they begin segmenting speech using a form of MSS. Alternatively, a finding that English learners have difficulty with weak/strong words would provide additional support for the view that they rely on something like MSS to segment words. In addition to exploring the ability of 7.5 month olds to segment weak/strong words, as in Part I, we examined the nature of the information that they extract about such words.

Experiment 7

If English learners develop a general ability to segment words from fluent speech at around 7.5 months of age, then they may do as well with weak/strong words as they do with strong/weak words. To explore this possibility, we decided to familiarize 7.5 month olds with pairs of weak/strong words and then test them on passages that either contained or did not contain the familiarized target words. The weak/strong target words selected for this study were ‘‘guitar,’’ ‘‘surprise,’’ ‘‘beret,’’ and ‘‘device.’’ Once again, the strong syllables of these words corresponded to lexical words in English. The weak syllables of these words included reduced, unstressed vowels. After the infants had listened to the familiarized target words (either ‘‘guitar’’ and ‘‘device’’ or ‘‘beret’’ and ‘‘surprise’’), they were tested on four six-sentence passages: two of which contained the familiarized targets in every sentence; two of which contained the same number of unfamiliar targets. As in our earlier studies, we predicted that if infants detected the familiarized targets in the passages, they would listen significantly longer to the passages containing these words.

Method

Participants. The participants were 24 American infants (15 males, 9 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 0 days (range: 31 weeks, 0 days, to 34 weeks, 6 days). To obtain the 24 infants for this study, it was necessary to test 34. Infants were excluded for the following reasons: crying (8) and looking times averaging less than 3 s to the passages (2).

Stimuli. The same female from western New York recorded four different six-sentence passages (see Table 4). She read the passages in a lively voice, as if reading to a small child. The recordings were made under the same conditions as those described for Experiment 1.

TABLE 4
Passages with Weak/Strong Words

Guitar passage
The man put away his old guitar. Your guitar is in the studio. That red guitar is brand new. The pink guitar is mine. Give the girl the plain guitar. Her guitar is too fancy.
Device passage
Your device can do a lot. Her device only fixes things. My new red device makes ice cream. The pink device sews clothes. We don’t need that old device. I think it is a plain device.
Beret passage
The lady is wearing an old beret. She gave her plain beret to the clerk. Your beret is colorful and new. The red beret belongs to Jacques. Your mother bought a pink beret. Her beret is nice, too.
Surprise passage
The big red surprise is for you. The small pink surprise is for Dawn. Your surprise will be fantastic. I think Dawn got the old surprise. Her surprise might not last long. At least she didn’t get a plain surprise.

The average duration of the passages was 18.46 s (ranging from 18.23 s for the ‘‘guitar’’ passage to 18.91 s for the ‘‘surprise’’ passage).

Acoustic analyses on the target words in the sentences indicated that the average duration of the first (unstressed) syllable (153 ms) was significantly shorter than that of the second (stressed) syllable (375 ms) ($F(1, 20) = 208.90$, $p < .0001$). The average pitch peaks of the first syllables of these target words (199 Hz) tended to be lower than those of the second syllables (211 Hz), but this difference was not significant ($F(1, 20) < 1.00$). For the individual target words, the average durations of the first and second syllables were 134 and 376 ms (guitar), 98 and 393 ms (device), 138 and 316 ms (beret), and 243 and 417 ms (surprise). The average pitch peaks of the first and second syllables were 247 and 205 Hz (guitar), 194 and 212 Hz (device), 173 and 181 Hz (beret), and 184 and 245 Hz (surprise). Thus, the strong syllables of the weak/strong targets in sentences were longer but did not necessarily have higher pitch peaks than did the weak syllables.

Once it was determined that the passages were acceptable, the same woman was asked to record versions of the isolated words to be used during the familiarization phase of the experiment. For each target word, the talker was asked to repeat the item with some variation 15 times in a row, in a lively voice, and as if naming the object for an infant. The average duration of the lists was 21.22 s (ranging from 20.74 s for the ‘‘device’’ list to 21.72 s for the ‘‘surprise’’ list).

The acoustic analyses for the isolated target words indicated an overall difference in duration for the first (160 ms) and second syllables (637 ms) that was highly significant ($F(1, 56) = 1788.98$, $p < .0001$). The lengthening of the final syllables for these words reflects the fact that not only were these syllables stressed but they were utterance-final (Klatt, 1976). The pitch peaks of the first syllables (316 Hz) were also significantly lower than those of the second syllables (376 Hz) ($F(1, 56) = 38.11$, $p < .0001$). Thus, strong syllables had both longer durations and higher pitch peaks than the weak syllables. For the individual target words, the average durations of the first and second syllables were 142 and 603 ms (guitar), 102 and 626 ms (device), 154 and 520 ms (beret), and 243 and 799 ms (surprise). The average pitch peaks of the first and second syllables were 386 and 350 Hz (guitar), 275 and 363 Hz (device), 279 and 406 Hz (beret), and 323 and 386 Hz (surprise).

Design. The design was essentially the same as that for Experiment 1, with the exception of the lists and the passages used. Half of the infants heard the words ‘‘guitar’’ and ‘‘device’’ during the familiarization phase, and the other half heard the words ‘‘beret’’ and ‘‘surprise.’’ During the test phase, all the infants heard four blocks of the same four passages. Each block contained a different random ordering of the passages corresponding to ‘‘guitar,’’ ‘‘device,’’ ‘‘beret,’’ and ‘‘surprise.’’

Apparatus. The same equipment was used as that in the previous experiments.

Procedure. This was the same as the one described for Experiment 1. The only difference was that infants were exposed to a pair of weak/strong words during familiarization, rather than to a pair of strong/weak words. The test period was carried out as in Experiment 1. However, new passages with weak/strong targets were substituted for the ones with strong/weak targets that appeared in Experiment 1.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Nine of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 7.19 s ($SD = 2.08$ s) for the passages with the familiarized words and 7.55 s ($SD = 2.30$ s) for the passages with the unfamiliar words. A paired *t* test indicated that this difference in listening times was not significant ($t(23) = -1.19$, $p < .25$; 95% CI: $-0.27 < 0.36 < 0.99$). Thus, 7.5 month olds familiarized with isolated versions of weak/strong target words did not appear to detect these same words when they occurred in the test passages.

The present findings for weak/strong words stand in sharp contrast to those of Experiment 1 for strong/weak words. Furthermore, the lack of a significant effect for the test items containing the familiarized targets is the first instance in which 7.5 month olds failed to detect whole word targets corresponding to ones in the familiarization period. To verify this apparent difference in the abilities of 7.5 month olds to segment strong/weak and weak/strong words from fluent speech, we submitted the data from Experiments 1 and 7 to an ANOVA of a 2 (Experiment) X 2 (Word Familiarity) mixed design. Neither the main effect of Experiment ($F(1, 46) < 1.00$), nor the main effect of Word Familiarity $F(1, 46) = 2.10$, $p < .20$) was significant. However, there was a significant interaction between these two factors ($F(1, 46) = 8.15$, $p < .007$), confirming that the 7.5 month olds were significantly better at segmenting strong/weak words than weak/strong words.

Previous studies had indicated that English-learning infants at this age detected monosyllabic words (Jusczyk & Aslin, 1995; Experiments 1 and 4) and bisyllabic strong/weak words (Experiments 1 and 2 of the present study). Can the infants' failure to detect weak/strong words in fluent speech contexts be attributable to a tendency to segment fluent speech at strong syllables, as is predicted by an MSS account? If so, then when a word such as ''guitar'' appears in a fluent speech context, infants may infer a word boundary at the onset of the strong syllable ''tar.'' To investigate this last possibility, we conducted the following experiment.

Experiment 8

Infants who segment weak/strong words at strong syllable boundaries may perceive the strong syllables of these words as monosyllabic words. Thus, when listening to the fluent speech passages in Experiment 7, the infants may have detected monosyllabic words such as ''tar'' and ''vice,'' rather than ''guitar'' and ''device.'' If this were true, then infants familiarized with strong syllables might actually match these to passages containing weak/strong words that include the familiarized strong syllable. To test this, we familiarized infants with pairs of strong syllables from the original weak/strong words. Half of the infants were familiarized with ''tar'' and ''vice'' and the other half with ''ray'' and ''prize.'' Then, the infants were tested on the four passages containing the weak/strong words ''guitar,'' ''device,'' ''beret,'' and ''surprise.'' A finding that infants listen significantly longer to the passages with the weak/strong words that correspond to the familiarized syllables would provide some additional support for the view that they use something like MSS to segment words from fluent speech.

Method

Participants. The participants were 24 American infants (12 males, 12 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 1 day (range: 30 weeks, 5 days, to 35 weeks, 0 days). To obtain the 24 infants for this study, it was necessary to test 31. Infants were excluded for the following reasons: crying (4), restlessness (2), and failure to look at the flashing lights (1).

Stimuli. The same female talker from western New York recorded 15 tokens each of the words ''tar,'' ''vice,'' ''ray,'' and ''prize.'' The words were recorded in the same manner and under the same recording conditions as the isolated word tokens in Experiment 1. The average duration of the lists was 22.50 s (ranging from 22.16 s for the ''tar'' list to 23.01 s for the ''prize'' list). Acoustic analyses of the isolated target words indicated that the average duration and average pitch peaks were the following: 768 ms and 383 Hz (tar), 859 ms and 387 Hz (vice), 706 ms and 337 Hz (ray), and 880 ms and 371 Hz (prize). In addition to the new lists of isolated words, the passages for ''guitar,'' ''device,'' ''beret,'' and ''surprise'' from Experiment 7 were used in the present study.

Design. During the familiarization period, on alternating trials, infants were exposed to repetitions of tokens of one of a pair of words produced in isolation. Half of the infants were familiarized with ''tar'' and ''vice'' for 30 s to each word. The other half of the infants were familiarized with ''ray'' and ''prize.'' During the test period, all the infants heard the four six-sentence test passages for the weak/strong words (see Table 3). The passages were randomized in each block. Each infant heard four blocks of test trials.

Apparatus. The same equipment was used as that in Experiment 1.

Procedure. With the exception of the fact that new lists of isolated words were used in the present experiment, the procedure was identical to that described for Experiment 7.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Nineteen of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 8.45 s (SD = 2.38 s) for the passages with the familiarized words and 6.80 s (SD = 1.85 s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was significant ($t(23) = 4.12$, $p < .0005$). Thus, the infants listened significantly longer to the passages containing the weak/strong words that included the familiarized monosyllabic words.

The present findings stand in contrast to those of Experiment 7, in which infants familiarized with weak/strong words did not listen longer to passages that included these words. Instead, infants in the present experiment who were familiarized with strong syllables apparently detected some correspondence between these items and the comparable weak/strong words in the passages. To confirm this tendency, we subjected the data from Experiments 7 and 8 to an ANOVA of 2 (Experiment) × 2 (Word Familiarity) mixed design. The main effect of Experiment was not significant ($F(1, 46) < 1.00$), but the main effect of Word Familiarity was ($F(1, 46) = 6.51$, $p < .05$). Most importantly, the interaction between these two factors was highly significant ($F(1, 46) = 16.00$, $p < .0005$), reflecting the fact that longer listening times to the passages corresponding to the targets occurred only after familiarization with the strong syllables.

These findings are certainly consistent with the MSS view that English learners use the location of strong syllables as an indicator of word onsets in fluent speech. To assess the robustness of these findings, we conducted another experiment in which we familiarized infants with the passages containing the bisyllabic target words and then tested them on repetitions of the strong syllables produced in isolation.

Experiment 9

Method

Participants. The participants were 24 American infants (14 males, 10 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 3 days (range: 30 weeks, 6 days, to 35 weeks, 1 day). To obtain the 24 infants for this study, it was necessary to test 32. Infants were excluded for the following reasons: crying (2), restlessness (3), parental interference with infants' responding during test trials (1), equipment failure (1), and failure to look at the flashing lights (1).

Stimuli. The same stimuli were used as those in Experiment 8.

Design. The design was essentially the same as that for Experiment 4, with the four weak/strong passages substituted for the strong/weak ones used in the earlier experiment. Infants were familiarized with either the ''guitar'' and ''device'' or the ''beret'' and ''surprise'' passages. During the test phase, all the infants heard three blocks of the same four lists of repeated, isolated tokens of the strong syllables corresponding to the ones in the weak/strong bisyllabic target words in the familiarization passages. Each block contained a different random ordering of the lists of the words ''tar,'' ''vice,'' ''ray,'' and ''prize.''

Apparatus. The same equipment was used as that in Experiment 1.

Procedure. With the exception of the fact that the passages and lists in the present experiment differed, the procedure was identical to that described for Experiment 4.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Sixteen of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 10.88 s ($SD = 3.76$ s) for the lists with the familiarized words and 9.74 s ($SD = 2.87$ s) for the lists with the unfamiliar words. A paired t test indicated that this difference was marginally significant by a two-tailed test ($t(23) = 1.80$, $p < .09$; 95% CI: $-0.17 < 1.14 < 2.45$). Although not as strong as those of the previous experiment, the present results are in the same direction. As a further check on this tendency, we analyzed the data from Experiment 8 and 9 using an ANOVA of 2 (Experiment) $\times$ 2 (Word Familiarity) mixed design. There was a significant main effect of Experiment ($F(1, 46) = 14.01$, $p < .001$), reflecting the fact that the overall listening times were longer in

Experiment 9. The main effect of Word Familiarity was also significant ($F(1, 46) = 13.86$, $p < .001$). However, the interaction between these two factors did not approach statistical significance ($F(1, 46) < 1.00$), reflecting the fact that infants in both experiments listened longer to the familiarized targets during the test phase. Thus taken together, the findings from Experiments 8 and 9 provide support for the view that infants apparently perceive a word boundary before the strong syllable of weak/strong words in fluent speech.

The pattern of results in the three experiments with weak/strong words is the opposite of those obtained in the experiments with strong/weak words. For the latter, significant listening preferences occurred to the passages with the familiarized words only when whole strong/weak words were used in both the familiarization and test periods. However, for weak/strong words, 7.5 month olds did not show a significant preference when they were familiarized with weak/strong words and tested on passages containing these same words. Rather, the infants displayed a tendency to match the passages with weak/strong words to just the strong syllables of these words. Why might infants identify strong syllables with weak/strong words in passages, but not with strong/weak words in passages? The answer may lie in the difference in the distributional contexts for the strong syllable in the weak/strong and strong/weak words. In particular, whenever a strong/weak word appears in a sentential context, its strong syllable is always followed by the same weak syllable (e.g., ‘‘ham’’ is always followed by ‘‘let’’). However, the frequency with which the same weak syllable follows the strong syllable of a weak/strong word is usually much lower. Thus, the ‘‘tar’’ from ‘‘guitar’’ might be followed by ‘‘is’’ on one occasion, by ‘‘has’’ on another, by a sentence boundary on another, etc. These differences in the contexts following the strong syllable of a weak/strong word may help to signal a word boundary after the strong syllable, as Brent and Cartwright’s (1996) INCDROP model predicts. Combined with the tendency to identify strong syllables with word onsets (in accord with the use of MSS), this distributional property identifying the end of the word would make ‘‘tar’’ pop out of the sentential context as a potential word. Moreover, as Saffran et al. (1996a; Aslin, Saffran, & Newport, 1998) demonstrate, infants at this age are sensitive to the frequency with which certain syllables are likely to follow one another.

If 7.5 month olds’ sensitivity to distributional contexts plays a role in how they respond to the contexts following the strong syllables of strong/weak and weak/strong words, it should be possible to affect their word segmentation abilities by altering the distributional contexts. The next two experiments investigated how altering these contexts affects the way that 7.5 month olds segment weak/strong words from fluent speech.

Experiment 10

One way to assess the impact that the distribution of syllables immediately following weak/strong words has on infants’ segmentation of words is to manipulate these contexts systematically. For this purpose, we rewrote the passages for each of the weak/strong words. In the new passages, a particular weak/strong target word was always followed by the same monosyllabic item. For example, ''guitar'' was always followed by ''is'' when it occurred in sentences in the new passage. Similarly, ''surprise'' was followed by ''in,'' ''beret'' by ''on,'' and ''device'' by ''to.'' Because the same syllable always followed the strong syllable of these weak/strong words in the passages, the co-occurrence relation between these syllables was as high as for that of the strong and weak syllables of the strong/weak words in the studies in Part I. Given that familiarization with strong syllables did not lead to longer listening times for strong/weak words that included these syllables, the weak/strong word contexts in the new passages may have a similar effect when infants are familiarized with just the strong syllables of weak/strong words. To test this possibility, infants were familiarized with a pair of new passages that included the sequences ''guitar is,'' and ''device to'' or ''beret on,'' and ''surprise in.'' Then they were tested on the strong syllables from weak/strong words (e.g., with ''tar'' and ''vice,'' or ''ray'' and ''prize''). A finding that infants listen significantly longer to the syllables corresponding to the weak/strong words in the familiarization passages would indicate that information about the following distributional context is not a critical factor in word segmentation for infants at this age.

Method

Participants. The participants were 24 American infants (14 males, 10 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 4 days (range: 30 weeks, 6 days, to 35 weeks, 0 days). To obtain the 24 infants for this study, it was necessary to test 26. Two infants were excluded for crying.

Stimuli. Four new test passages were created so as to follow each target word always with the same monosyllabic item (see Table 5). In the passages, ''guitar'' was always followed by ''is,'' ''device'' by ''to,'' ''beret'' by ''on,'' and ''surprise'' by ''in.'' The passages were recorded by the same woman from western New York who had recorded the passages in the previous experiments. The passages were recorded and digitized under the same conditions as those in Experiment 1. The average duration of the passages was 23.62 s (ranging from 23.12 s for the ''surprise in'' passage to 24.00 s for the ''beret on'' and ''guitar is'' passages).

Acoustic analyses of the target words in the sentences indicated that the average duration of the first (unstressed) syllable (152 ms) was significantly shorter than that of the second (stressed) syllable (372 ms) ($F(1, 20) = 450.33$, $p < .0001$). The average pitch peaks of the first syllables of these target words (215 Hz) were significantly lower than those of the second syllables (246 Hz) ($F(1, 20) = 4.74$, $p < .05$). With respect to the individual target words, the average durations of the first and second syllables were 155 and 404 ms (guitar), 92 and 397 ms (device), 137 and 274 ms (beret), and 226 and 411 ms (surprise). The average pitch peaks of the first and second syllables were 218 and 250 Hz (guitar), 205 and 227 Hz (device), 191 and 224 Hz (beret), and 246 and 282 Hz (surprise). Thus, the strong syllables of the weak/strong targets in sentences were longer and had higher pitch peaks than the weak syllables.

In addition to the new familiarization passage, the test materials were the lists of isolated tokens of ''tar,'' ''vice,'' ''ray,'' and ''prize'' that were used in Experiment 9.

Design. The design was essentially the same as that for Experiment 9, with the exception that the new passages were substituted for the original weak/strong word passages. Infants were familiarized with pairs of the new passages (i.e., with either the ''guitar is'' and ''device

TABLE 5
Passages with Weak/Strong Target Words Followed by the Same Monosyllabic Word

''Guitar is'' passage
Your guitar is really a fine instrument. But she says that the old guitar is great. In the attic, her guitar is hidden away. My pink guitar is not nearly as special. I think that a red guitar is better looking. But if you want to play, a plain guitar is fine.

''Device to'' passage
She looks for her device to start the project. That old device to bake the bread is broken. It would be wise to try your device to begin. Give the red device to him if you are busy. A plain device to do the job is better. We should bring the pink device to the rescue.

''Beret on'' passage
Susie is buying her beret on credit. That red beret on the shelf might do. She asked the clerk to put the pink beret on. It was next to the plain beret on the counter. The old beret on the model is my favorite. Your beret on her is very chic.

''Surprise in'' passage
We've got a big surprise in store for you. Her surprise in the barn is big, too. But it will be a very plain surprise in the box. Your surprise in the closet is very exciting. We hid this red surprise in Joan's house. The pink surprise in the hallway will astonish you.

to'' passages or with the ''beret on'' and ''surprise in'' passages). During the test phase, all the infants heard three blocks of the same four test lists. Each block contained a different random ordering of the lists corresponding to ''tar,'' ''vice,'' ''ray,'' and ''prize.''

Apparatus. The same equipment was used as that in the previous experiments.

Procedure. This was the same as the one described for Experiment 9. However, new familiarization passages with weak/strong targets were substituted for the ones with weak/strong targets that appeared in Experiment 9.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Ten of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 9.68 s (SD = 4.26 s) for the lists with the familiarized words and 10.60 s (SD = 3.69 s) for the lists with the unfamiliar words. A paired t test indicated that this difference was not significant ($t(23) = -0.97$, $p < .35$; 95% CI: $-1.94 < 0.92 < 2.88$).

In contrast to Experiment 9, infants in the present experiment did not show any significant tendency to listen longer to the test lists that included the words that had appeared in the familiarization passages. To confirm this difference, we submitted the data from Experiments 9 and 10 to an ANOVA of a 2 (Experiment) $\times$ 2 (Word Familiarity) mixed design. Neither main effect was significant ($F(1, 46) < 1.00$). However, there was a marginally significant interaction between these two factors ($F(1, 46) = 3.26$, $p < .08$), reflecting the fact that longer listening times to the syllables corresponding to the targets occurred only for the passages in which the weak/strong words were not always followed by the same monosyllable (i.e., the passages used in Experiment 9).

Thus, the change in the sentential context for the target words in the passages affected the way in which the infants segmented the words in the passages. In particular, the fact that the weak/strong targets were always followed by the same monosyllabic item may have led infants to treat the sequence of the strong syllable plus following monosyllable as parts of the same bisyllabic word. Acoustic analyses of the strong syllable compared to the syllable that consistently followed it offer some support for this view. The average duration of the strong syllables (372 ms) was significantly longer than that of the following syllable (194 ms) ($F(1, 20) = 118.12$, $p < .0001$). The strong syllables also tended to have a higher pitch peak (246 Hz) than that of the following syllable (228 Hz), although this difference was not significant ($F(1, 20) = 1.15$, $p < .35$). Thus, the duration and pitch characteristics of these syllable sequences in the sentences are similar to those for strong/weak words in similar contexts (e.g., as in Experiment 1).

Infants in the present experiment behaved much like those in Experiment 4, where infants did not listen significantly longer to ‘‘king’’ and ‘‘ham’’ after being familiarized with the ‘‘kingdom’’ and ‘‘hamlet’’ passages. Nevertheless support for this position would be stronger if it could be demonstrated that infants actually do segment sequences such as ‘‘taris’’ from the passages used in the present experiment. Consequently, we conducted the following experiment to explore this possibility.

Experiment 11

One way to determine whether the distributional contexts following strong syllables provide English learners with information about the ends of words is to determine whether they tend to treat strong/weak syllable sequences that co-occur frequently as potential words. Saffran et al.’s (1996) results suggest that such co-occurrence relations do figure in the word segmentation abilities of English-learning 8 month olds. Specifically, the infants distinguished syllable sequences that co-occurred frequently from ones that co-occurred infrequently. If the same pattern held for infants tested with the new weak/strong word passages in the previous experiment, they may have been expecting lexical items composed of the strong syllable and its following monosyllable, such as ‘‘taris’’ or ‘‘rayon.’’ To explore this hypothesis, we familiarized the infants with pairs of the new weak/strong passages and tested them on lists consisting of repetitions of the items ‘‘taris,’’ ‘‘viceto,’’ ‘‘rayon,’’ and ‘‘prizin.’’ If infants use information about the distributional context following a strong syllable to determine the ends of words, infants familiarized with the ‘‘guitar is’’ and ‘‘device to’’ passages should listen significantly longer to the ‘‘taris’’ and ‘‘viceto’’ lists than to the ‘‘rayon’’ and ''prizin'' lists (and vice versa for familiarization with the ''beret on'' and ''surprise in'' passages).

Method

Participants. The participants were 24 American infants (11 males, 13 females). The infants were approximately 7.5 months old, with a mean age of 32 weeks, 3 days (range: 30 weeks, 6 days, to 34 weeks, 0 days). To obtain the 24 infants for this study, it was necessary to test 31. Infants were excluded for crying (6) and restlessness (1).

Stimuli. Four new test lists were created. The same woman from western New York recorded 15 different repetitions each of the items ''taris,'' ''viceto,'' ''rayon,'' and ''prizin.'' The talker was asked to produce these items as if they were two-syllable words with an accent on the first syllable. The recordings were made under the same conditions as described for Experiment 1. The average duration of the lists was 21.72 s (ranging from 21.28 s for the ''rayon'' list to 21.96 s for the ''viceto'' list).

The acoustic analyses for the isolated target words indicated that there was a significant difference in duration for the first (462 ms) and second syllables (381 ms) ($F(1, 56) = 87.40$, $p < .0001$). Similarly, pitch peaks of the first syllables (361 Hz) were, once again, significantly higher than those of the second syllables (288 Hz) ($F(1, 56) = 16.90$, $p < .0001$). Thus, the first (stressed) syllables had longer durations and higher pitch peaks than the second (unstressed) syllables. For the individual target words, the average durations of the first and second syllables were 435 and 367 ms (taris), 447 and 420 ms (viceto), 419 and 390 ms (rayon), and 550 and 347 ms (prizin). The average pitch peaks of the first and second syllables were 356 and 285 Hz (taris), 372 and 309 Hz (viceto), 327 and 291 Hz (rayon), and 388 and 268 Hz (prizin). In addition to the new lists, the new weak/strong passages from Experiment 10 were used.

Design. The design was identical to that of Experiment 10, with the exception that four new test lists were substituted for the ones used in the earlier experiment. As in the previous experiment, the infants were familiarized with a pair of passages. Half of the infants heard the ''guitar is'' and ''device to'' passages; the other half heard the ''beret on'' and ''surprise in'' passages. During the test period, all infants heard four blocks of the four test lists. Each block contained a different random ordering of the lists corresponding to ''taris,'' ''viceto,'' ''rayon,'' and ''prizin.''

Apparatus. The same equipment was used as that in the previous experiments.

Procedure. This was the same as the one described for Experiment 10. However, new test lists with strong/weak targets were substituted for the ones with strong syllable targets that appeared in Experiment 10.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Eighteen of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 10.94 s ($SD = 2.20$ s) for the lists with the familiarized words and 8.95 s ($SD = 2.44$ s) for the lists with the unfamiliar words. A paired t test indicated that this difference was significant ($t(23) = 3.06$, $p < .006$). Thus, the infants listened significantly longer to the lists containing the strong/weak patterns that occurred in the familiarization passages.

Infants in the present study who were familiarized with passages in which weak/strong targets were always followed by the same monosyllabic word reacted as though they detected words with a strong/weak pattern. In this sense, they missegmented words from the passages. However, the infants were acting in accord with the distributional cues provided by the sentential contexts, because the strong syllable in the weak/strong target was followed by the same monosyllabic word in every context. Given their limited vocabularies, plus the distributional evidence, it is not surprising that infants segmented the input in this way.

The present findings offer further evidence that English-learning 7.5 month olds identify strong syllables with onsets of words in fluent speech. However, the results also provide additional support for the view that distributional cues are used by infants in word segmentation (Aslin et al., 1998; Brent & Cartwright, 1996; Saffran et al., 1996a). Taken together, the results of Experiments 10 and 11 suggest that distributional cues provide language learners with information about the ends of words in fluent speech.

Discussion of Part II

The overall pattern of results from these experiments investigating English-learning 7.5 month olds' segmentation of weak/strong words from fluent speech is consistent with what is expected if they rely on a procedure similar to the one proposed in MSS (Table 6). In particular, not only do infants at this age have difficulty detecting weak/strong words in fluent speech, but they also demonstrate a tendency to segment such words at strong syllables. Moreover, when the distributional contexts favored the association of a following weak syllable to a strong syllable, the infants responded as though they perceived a strong/weak word in these contexts.

If the present studies provide additional support for the view that infants tend to begin segmenting words at onsets of strong syllables, they also bolster

TABLE 6
Summary of Results of Experiments 7–11

Experiment	Familiarization stimuli	Test stimuli	Evidence of segmentation?
7	Isolated W/S words	Passages with W/S words	No
8	Isolated strong syllables	Passages with W/S words	Yes
9	Passages with W/S words	Isolated strong syllables	Yes
10	Passages with W/S words and following weak syllable	Isolated strong syllables	No
11	Passages with W/S words and following weak syllable	Isolated strong syllables and following weak syllable	Yes

the case for the importance of distributional cues in word segmentation. In processing fluent speech, English-learning infants may open a window for a word candidate when they encounter a strong syllable. This may simply be a reflection of the fact that strong syllables are more perceptually salient than weak syllables in the stream of speech. What information is included after the strong syllable (i.e., whether the word is a monosyllable or multisyllabic) apparently depends on the distributional contexts following that syllable. Information that the strong syllable consistently co-occurs with a particular following syllable is a potential indicator that the word is multisyllabic. Thus, at this early stage of development of English learners' word segmentation abilities, stress-based and distributional cues may complement each other. Although stress-based cues such as the location of strong syllables may be important in determining where words begin, distributional cues may help infants determine where candidate words end.[3]

One problem with the picture just presented is that continued reliance on the locus of strong syllables to indicate word onsets would ensure that English learners missegment words beginning with weak syllables. What good is a strategy, such as MSS, if it continually leads infants to missegment certain kinds of words in the input? There are two ways to respond to this critique. The first is that, as noted earlier, the majority of the words that English-learning infants are likely to hear do begin with strong syllables. Hence, they will be right more often than wrong in segmenting words from fluent speech. However, there is also another potential benefit that accrues to merely segmenting the input into smaller word-like chunks. These smaller chunks may allow infants to learn about other potential cues to word boundaries, such as how allophones and phonotactic sequences tend to be distributed within these chunks (Jusczyk, 1998). Indeed, there is some evidence that English-learning infants develop some ability to use allophonic cues to word boundaries at some point between 9 and 10.5 months of age (Jusczyk et al., in press). Similarly, in their investigation, Myers et al. (1996) observed that English-learning 10.5 month olds may have used phonotactic cues to detect when weak/strong words were interrupted in fluent speech passages. More recently, Mattys et al. (1999) found that English-learning 9 month olds

[3] Further support for this position comes from a recent investigation of words with strong/weak/strong stress patterns (Houston, Santelmann, & Jusczyk, in preparation). In particular, 7.5 month olds showed no tendency to impose a word boundary before the last strong syllable of words such as ''parachute.'' Thus, the infants did not segment such items into two separate words such as ''para'' and ''chute,'' as they might have if they relied only on MSS and imposed word boundaries at all strong syllable onsets. Thus, the distributional property of the consistent co-occurrence of the final strong syllable with the preceding strong/weak pattern appears to have countered the tendency to infer a word boundary prior to this final strong syllable. Thus, although the locus of strong syllables may provide infants at this age with clues as to where words may begin, the distributional cues seem to play a more important role in determining where words end.

demonstrated some knowledge of how certain phonotactic sequences typically line up with the boundaries of words. Given the results of these investigations with older infants, it seemed worthwhile to investigate whether English-learning 10.5 month olds demonstrate any ability to segment weak/strong words from fluent speech.

PART III: HOW 10.5 MONTH OLDS RESPOND TO WEAK/STRONG WORDS IN FLUENT SPEECH

Although English-learning 7.5 month olds demonstrate some ability to segment monosyllabic words and words with strong/weak patterns, they are less successful with words with weak/strong stress patterns. Reliance on a strategy, such as MSS, in which onsets of words are identified with the occurrence of strong syllables may be responsible for the difficulties that infants at this age have in detecting weak/strong words in fluent speech. Nevertheless, in order to become a mature hearer/speaker of English, infants eventually have to segment weak/strong words correctly. The following series of studies was undertaken to investigate whether 10.5 month olds might be more successful in segmenting weak/strong words from fluent speech. Once again, we were interested in the kind of information that infants at this age recover about weak/strong words. For example, are they able to segment weak/strong words or only a portion of these words, such as their strong syllable?

Experiment 12

The first step in this series of studies was to determine whether English-learning 10.5 month olds display any ability to segment weak/strong words in fluent speech. Accordingly, we began by familiarizing 10.5 month olds with pairs of weak/strong words such as ‘‘guitar’’ and ‘‘device’’ (or with ‘‘beret’’ and ‘‘surprise’’) and then tested them on four passages: two of which included the familiarized words and two of which did not. A finding that 10.5 month olds listen significantly longer to the passages containing the familiarized words would be an indication that they were able to segment weak/strong words from fluent speech.

Method

Participants. The participants were 24 American infants (12 males, 12 females). The infants were approximately 10.5 months old, with a mean age of 45 weeks, 4 days (range:43 weeks, 1 day, to 48 weeks, 0 days). To obtain the 24 infants for this study, it was necessary to test 29. Infants were excluded for crying (3) and restlessness (2).

Stimuli. The stimuli were identical to those used in Experiment 7.

Design. The design was the same as that in Experiment 7. The infants were familiarized with pairs of weak/strong words (half with ‘‘guitar’’ and ‘‘device’’; the other half with ‘‘beret’’ and ‘‘surprise’’). During the test period, all the infants heard four blocks of the test passages for ''guitar,'' ''device,'' ''beret,'' and ''surprise.'' The passages in each block occurred in a different random order.

Apparatus and procedure. These were the same as in Experiment 7.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Eighteen of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 7.48 s (SD = 2.18 s) for the passages with the familiarized words and 6.17 s (SD = 2.17 s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was significant ($t(23) = 4.19$, $p < .0005$). Thus, 10.5 month olds familiarized with isolated versions of weak/strong target words listened significantly longer to the test passages that included these words.

In contrast to 7.5 month olds, English-learning 10.5 months olds do seem to have some ability to detect familiarized weak/strong words in fluent speech passages. To verify this apparent developmental difference, we conducted an ANOVA of a 2 (Age) × 2 (Word Familiarity) mixed design using the data from the 10.5 month olds along with those from 7.5 month olds in Experiment 7. The main effect of Word Familiarity was significant ($F(1, 46) = 4.70$, $p < .05$) indicating that, overall, listening times were longer to the passages with the familiarized words. The main effect of Age was not significant ($F(1, 46) < 1.00$), but the critical interaction between Age and Word Familiarity was significant ($F(1, 46) = 14.70$, $p < .0005$), an indication that only the older infants showed a reliable Word Familiarity effect. Hence, this analysis supports the view that the ability of English learners to segment weak/strong words from fluent speech develops between 7.5 and 10.5 months of age.

The present findings provide an indication that 10.5 month olds have some ability to segment weak/strong words from fluent speech. However, to get a clearer idea of the extent of these older infants' abilities, it seemed useful to examine how they would respond when familiarized with just the strong syllables of these items. Given that at a younger age, English learners responded to just the strong syllables of these words in fluent speech, might there be some residual tendency to do so in the older infants? To explore this possibility, we familiarized a new group of 10.5 month olds with pairs of strong syllables from the weak/strong words (i.e., with either ''tar'' and ''vice'' or with ''ray'' and ''prize'') and then tested them on the passages containing ''guitar,'' ''device,'' ''beret,'' and ''surprise.'' Thus the design of this experiment replicates that of Experiment 8 with the 7.5 month olds. If 10.5 month olds retain some residual tendency to respond to the strong syllables of these words in fluent speech, they should have significantly longer listening times to the passages that contain the familiarized strong syllables.

Experiment 13

Method

Participants. The participants were 24 American infants (13 males, 11 females). The infants were approximately 10.5 months old, with a mean age of 45 weeks, 4 days (range: 42 weeks, 5 days, to 49 weeks, 6 days). To obtain the 24 infants for this study, it was necessary to test 28. Infants were excluded for the following reasons: crying (1), restlessness (1), looking times averaged less than 3 s (1), and parental interference with infants' responding during test trials (1).

Stimuli. The stimuli were identical to the ones used in Experiment 8.

Design. This was the same as the one in Experiment 8. Infants were familiarized with pairs of strong syllables from the weak/strong words. Half of the infants were familiarized with ''tar'' and ''vice'' and the other half with ''ray'' and ''prize.'' During the test period, the test passages for ''guitar,'' ''device,'' ''beret,'' and ''surprise'' were played. Infants heard four blocks of test passages, with a different random order of the passages in each block.

Apparatus and procedure. These were the same as those for Experiment 8.

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Thirteen of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 7.36 s ($SD = 2.47$ s) for the passages with the familiarized words and 6.79 s ($SD = 2.46$ s) for the passages with the unfamiliar words. A paired t test indicated that this difference in listening times was not significant ($t(23) = 1.21$, $p < .25$; 95% CI: $-0.41 < 0.57 < 1.55$). Thus, the infants did not listen significantly longer to the passages containing the weak/strong words that included the strong syllables from the familiarization period.

Once again, the behavior of the 10.5 month olds contrasted with that of the 7.5 month olds. The older infants displayed no significant tendency to respond to the passages with weak/strong words that corresponded to the strong syllables heard during familiarization. To verify this developmental trend, we conducted an ANOVA of a 2 (Age) $\times$ 2 (Word Familiarity) mixed design using the data from the 10.5 month olds along with those from 7.5 month olds in Experiment 8. The main effect of Word Familiarity was significant ($F(1, 46) = 12.85$, $p < .001$), indicating that, overall, listening times were longer to the passages with the familiarized words. The main effect of Age was not significant ($F(1, 46) < 1.00$), and the critical interaction between Age and Word Familiarity was only marginally significant ($F(1, 46) = 3.04$, $p < .09$). Although not as robust as in the previous experiment, the marginal interaction provides some further indication of a developmental trend in word segmentation skills of English learners between 7.5 and 10.5 months of age.

Therefore, in contrast to 7.5 month olds, 10.5-month-old English learners do display some ability to segment weak/strong words at the weak syllable, as opposed to the strong syllable. In this sense, their word segmentation abilities are closer to those of mature English listeners. Another characteristic that we observed of 7.5 month olds was that they were strongly affected by the distributional contexts following the strong syllables of weak/strong words. Does this tendency also hold for the older infants, or might they use other information to locate the ends of words? To investigate this matter, we decided to replicate Experiment 11 with 10.5 month olds. Specifically, we familiarized the infants with the passages in which the weak/strong words were always followed by the same monosyllable (i.e., ''guitar'' by ''is,'' ''device'' by ''to,'' etc.). During the test period, infants heard the lists with repetitions of the items ''taris,'' ''viceto,'' ''rayon,'' and ''prizin.'' If 10.5 month olds still rely primarily on distributional cues to determine the ends of words, they should listen significantly longer to the lists with the items that occurred in the familiarization passages.

Experiment 14

Method

Participants. The participants were 24 American infants (17 males, 7 females). The infants were approximately 10.5 months old, with a mean age of 45 weeks, 0 days (range: 43 weeks, 3 days, to 46 weeks, 3 days). To obtain the 24 infants for this study, it was necessary to test 27. Infants were excluded for crying (1) and restlessness (2).

Stimuli. The stimuli were identical to the ones used in Experiment 11.

Design. This was the same as the one in Experiment 11. The infants were familiarized with either the ''guitar is'' and ''device to'' passages or with the ''beret on'' and ''surprise in'' passages. During the test period, all infants heard four blocks of the four test lists. Each block contained a different random ordering of the lists corresponding to ''taris,'' ''viceto,'' ''rayon,'' and ''prizin.''

Apparatus. The same equipment was used as that in the previous experiments.

Procedure. This was the same as that described for Experiment 11.

Results and Discussion

Mean listening times to the four different word lists were calculated for each infant across the three blocks of trials. The mean listening times were averaged for the two lists corresponding to the familiarization period and for the two lists of unfamiliar words. Twelve of the 24 infants had longer average listening times for the lists containing the words from the familiarized passages. Across all subjects, the average listening times were 8.68 s (SD = 3.89 s) for the lists with the familiarized words and 8.73 s (SD = 3.52 s) for the lists with the unfamiliar words. A paired t test indicated that this difference was not significant ($t(23) = -0.09$, $p < .95$; 95% CI: $-1.15 < 0.05 < 1.25$). Thus, in contrast to the 7.5 month olds, the 10.5

month olds showed no tendency to listen longer to the lists containing the strong/weak patterns that occurred in the familiarization passages. To confirm this developmental trend, we conducted an ANOVA of a 2 (Age) × 2 (Word Familiarity) mixed design using the data from the 10.5 month olds along with those from 7.5 month olds in Experiment 11. The main effect of word familiarity was significant ($F(1, 46) = 4.94$, $p < .05$), indicating that, overall, listening times were longer to the passages with the familiarized words. The main effect of Age was not significant ($F(1, 46) = 2.54$, $p < .15$), but the critical interaction between Age and Word Familiarity was significant ($F(1, 46) = 5.49$, $p < .025$). Thus, there is further evidence of a developmental change in English learners' word segmentation skills between 7.5 and 10.5 months of age.

Even when the distributional contexts suggested a possible link between two successive syllables from different words, 10.5 month olds did not display a tendency to missegment words from the passages. There are a number of potential sources of information that infants could draw on to avoid missegmenting words in such contexts. Before considering some of these, it seemed worthwhile to determine whether 10.5 month olds do correctly segment words that occur in such contexts. In other words, do 10.5 month olds who hear a ''guitar is'' passage correctly segment ''guitar''? To investigate this issue, we conducted the following experiment in which infants were familiarized with pairs of weak/strong words (either with ''guitar'' and ''device'') or ''beret'' and ''surprise'' and were tested on the ''guitar is,'' ''device to,'' ''beret on,'' and ''surprise in'' passages. If 10.5 month olds are able to segment weak/strong words in these contexts, they should listen significantly longer to the passages containing the familiarized weak/strong words.

Experiment 15

Method

Participants. The participants were 24 American infants (8 males, 16 females). The infants were approximately 10.5 months old, with a mean age of 45 weeks, 6 days (range: 44 weeks, 3 days, to 49 weeks, 6 days). To obtain the 24 infants for this study, it was necessary to test 30. Infants were excluded for the following reasons: restlessness (3), looking times averaging less than 3 s (2), and failure to look at the flashing lights (1).

Stimuli. The stimuli for the familiarization period were the repetitions of the isolated versions of the words ''guitar,'' ''device,'' ''beret,'' and ''surprise'' that had originally been used in Experiment 7. The test period stimuli were the ''guitar is,'' ''device to,'' ''beret on,'' and ''surprise in'' passages that had originally been used in Experiment 10.

Design. Half of the infants heard the words ''guitar'' and ''device'' during the familiarization phase and the other half heard the words ''beret'' and ''surprise.'' During the test phase, all the infants heard four blocks of the same four passages. Each block contained a different random ordering of the passages corresponding to ''guitar is,'' ''device to,'' ''beret on,'' and ''surprise in.''

Apparatus. The same equipment was used as in the previous experiments.

Procedure. This was essentially the same as the one for Experiment 7. The infants were familiarized with pairs of isolated weak/strong words. The main difference between this experiment and Experiment 7 was that during the test period, the passages were the ‘‘guitar is,’’ ‘‘device to,’’ ‘‘beret on,’’ and ‘‘surprise in’’ passages that were originally used in Experiment 10 (see Table 5).

Results and Discussion

Mean listening times to the four different passages were calculated for each infant across the four blocks of trials. The mean listening times were averaged for passages containing the familiar words and for the ones containing the unfamiliar words. Twenty of the 24 infants had longer average listening times for the passages containing the familiarized words. Across all infants, the average listening times were 8.69 s ($SD = 2.95$ s) for the passages with the familiarized words and 6.72 s ($SD = 2.19$ s) for the passages with the unfamiliar words. A paired *t* test indicated that this difference in listening times was significant ($t(23) = 5.05$, $p < .001$). Thus, the 10.5 month olds correctly segmented the weak/strong words from these contexts.

The present results provide further evidence that 10.5 month olds are capable of segmenting weak/strong words from fluent speech, even in contexts in which there are potentially misleading distributional cues. How were these older infants able to segment weak/strong words correctly from these contexts? Clearly, the 10.5 month olds are relying on different sources of information than are 7.5 month olds. One possible explanation for the greater success of the older infants is that they may have learned to recognize some of the monosyllables (i.e., ‘‘is,’’ ‘‘to,’’ ‘‘on,’’ and ‘‘in’’) that followed the strong syllables of the weak/strong words. Their prior knowledge of these items could have then been used to segment the sequence that included the weak/strong word, much as Brent and Cartwright’s (1996) INCDROP model predicts. However, another possibility is that 10.5 month olds are sensitive to other cues, such as phonotactic sequences and context-sensitive allophones that point to the presence or the absence of a word boundary between the successive items. With respect to the phonotactic cues, we simply note that in four of the sentential contexts (i.e., ‘‘old,’’ ‘‘pink,’’ ‘‘red,’’ ‘‘plain’’), the word preceding the target item ends in a segment that cannot be combined with the initial segment of the targets to form a legal onset cluster for syllables in English. Hence, infants might infer a boundary between the ends of these words and the following target items in four of the six sentential contexts in the passages. Thus, these types of cues might have helped infants in detecting the onsets of weak/strong words, but not the offsets of these words.

Let us now consider the possibility that infants might also have used allophonic cues. Jusczyk et al. (in press) found evidence that English-learning infants at this age can use allophonic cues as markers of word boundaries in fluent speech. To determine if there were potential allophonic cues to the word boundaries in the passages, we conducted acoustic analyses of the critical passages and of the isolated words used in Experiment 14. In particular, for the targets in the passages, we focused on information in the vicinity of the syllable boundaries between the strong syllable of the weak/strong targets and the weak syllable that consistently followed this syllable in the passages (e.g., ‘‘tar’’ and ‘‘is’’ from the ‘‘guitar is’’ passage). We made comparable measurements for the ‘‘taris,’’ ‘‘viceto,’’ ‘‘rayon,’’ and ‘‘prizin’’ tokens that were produced as isolated words. Because the words produced in isolation had considerably longer durations than the comparable items in the passages, whenever we compared durational differences we first normalized the durations by dividing them by the overall length of the two-syllable sequence of which they were a part. Then the resulting values were used for any comparisons of durational differences in the isolated word and sentential contexts that are described below.

With respect to the various targets, there were significant acoustic differences that the 10.5 month olds could potentially use to distinguish between cases in which the strong and weak syllables were produced as a single word (as in the isolated ‘‘taris’’) from those in which the two syllables were adjacent, but parts of two different words (as in ‘‘guitar is’’). For instance, when ‘‘taris’’ was produced as an isolated word, the duration of the second vowel, [I], was significantly longer ($t(19) = 6.93$, $p < .0001$) than that in the ‘‘guitar is’’ sequence in the passage. In addition, there was a silent pause averaging 57.5 ms that was present between the final [r] of ‘‘guitar’’ and the initial [I] of ‘‘is,’’ but no evidence of a comparable pause for the isolated ‘‘taris’’ tokens. The critical properties for the isolated ‘‘viceto’’ and ‘‘device to’’ in the passages were the closure duration and burst duration for [t] in the different contexts. In particular, the [t] in ‘‘device to’’ sequences in the passages had significantly longer closure and burst than those for the [t] in the isolated ‘‘viceto’’ tokens ($t(19) = 6.02$, $p < .0001$ and $t(19) = 2.21$, $p < .05$), respectively. A short pause (averaging 43 ms) was observed between the successive syllables in the ‘‘beret on’’ passage, but not between the two syllables in the isolated ‘‘rayon’’ tokens. Another acoustic property distinguishing this particular pair was that the vowel in the strong syllable [e^y] was significantly longer in ‘‘rayon’’ than it was in the ‘‘beret on’’ passages ($t(19) = 2.68$, $p < .02$). Finally, for the isolated ‘‘prizin’’ tokens compared with the same syllables in the ‘‘surprise in’’ passages, there was evidence of a significant difference in the duration of the vowel [I] in the weak syllable. Specifically, the vowel was significantly longer when produced as an isolated ‘‘prizin’’ ($t(19) = 5.38$, $p < .0001$). This last finding mirrors the one observed for ‘‘taris’’ vs. ‘‘guitar is.’’ Thus, there is information in the speech stream that infants could potentially draw on to avoid segmenting ‘‘guitar is’’ as ‘‘gui taris.’’ Evidently, English-learning 10.5 month olds were able to use such

TABLE 7
Summary of Results of Experiments 12–15

Experiment	Familiarization stimuli	Test stimuli	Evidence of segmentation?
12	Isolated W/S words	Passages with W/S words	Yes
13	Isolated strong syllables	Passages with W/S words	No
14	Passages with W/S words and following weak syllable	Isolated strong syllables and following weak syllable	No
15	Isolated W/S words	Passages with W/S words and following weak syllable	Yes

information to segment ‘‘guitar,’’ rather than ‘‘taris,’’ from the ‘‘guitar is’’ passages.

Discussion of Part III

The studies described in this section demonstrate that 10.5 month olds are quite successful in segmenting weak/strong words from fluent speech (Table 7). In contrast to 7.5 month olds, when familiarized with weak/strong words, 10.5 month olds listened significantly longer to the passages containing these words. They did not show the tendency manifested by 7.5 month olds to identify strong syllables with weak/strong words in passages. Nor did they missegment the ends of weak/strong words when these were always followed by the same monosyllabic word. These older infants have moved away from a complete reliance on strong syllables to indicate word onsets. Clearly, they draw on other sources of information, such as allophonic or phonotactic cues, to indicate the onsets of words beginning with weak syllables. In many respects, then, English-learning 10.5 month olds display the kinds of word segmentation abilities characteristic of fluent speakers/hearers of the language.

GENERAL DISCUSSION

The pattern of results across the whole series of experiments indicates that 7.5 month olds display some ability to segment strong/weak words from fluent speech contexts. Furthermore, they do seem to respond to the whole strong/weak words rather than to a salient portion of these words, such as their strong syllables. Specifically, in Experiments 3–6, in which strong syllables were used during familiarization but strong/weak words during testing (or vice versa), no significant listening preferences occurred for the materials that included the familiarized targets. In contrast to their success in segmenting strong/weak words, 7.5 month olds had difficulty with weak/strong words. Infants familiarized with weak/strong words did not listen significantly longer to the passages that included these words. Instead, 7.5 month olds appeared to segment the weak/strong words in the passages at the strong syllables. Thus, significant listening preferences for the familiarized targets emerged only when 7.5 month olds were familiarized with the strong syllables and then tested on the passages with the weak/strong words or vice versa. Thus, across both the strong/weak and weak/strong words, 7.5 month olds displayed a tendency to respond to strong syllables as markers of the onsets of new words in fluent speech.

The studies with 7.5 month olds also provided support for the view that infants at this age use distributional cues in segmenting words from fluent speech. The importance of distributional cues was most clear in how the infants responded to weak/strong items that were consistently followed by a particular monosyllable. Infants appeared to treat these contexts as evidence for the occurrence of a strong/weak word, thus linking the final syllable of a weak/strong word to a weakly stressed following monosyllabic word. In fact, when the weak/strong words were consistently followed by the same monosyllabic word, the infants no longer responded to just the strong syllables of the weak/strong words. Rather they responded as had the infants who had been familiarized with strong/weak words and tested on strong syllables. One interpretation of this pattern of results is that 7.5 month olds may treat strong syllables as marking the onset of new words in fluent speech, but that they use distributional cues to determine the likely ends of these words. Evidence that a strong syllable is consistently followed by one or more syllables may be an indication that the potential word is multisyllabic.

Although the skills of 7.5 month olds may be only a starting point for successful word segmentation in English, the abilities of 10.5 month olds appear to be closer to those of mature listeners. In particular, 10.5 month olds familiarized with weak/strong words listened significantly longer to passages containing these words. In fact, they responded to the whole weak/strong words in fluent speech and not just to the strong syllables of these words. Moreover, in contrast to the 7.5 month olds, these older infants still were able to segment weak/strong words from contexts with potentially misleading distributional cues about the ends of these words. The greater success of 10.5 month olds in locating the boundaries of weak/strong words in fluent speech appears to derive from increased sensitivity to other potential cues to word boundaries such as allophones.

The present study has some interesting implications for understanding how word segmentation skills develop. Given that word segmentation has not been noted earlier than around 7.5 months of age for English learners (Jusczyk & Aslin, 1995), it appears that infants may initially use strong syllables as potential markers of new word onsets in fluent speech. Sensitivity to the predominant stress pattern of English words has been shown to develop between 6 and 9 months (Jusczyk et al. 1993a; Turk et al., 1995), and evidently learners begin using this information in segmenting words. However, there is a potential paradox with an account such as this. How can a learner identify the predominant stress pattern of words in the native language without already having some ability to segment fluent speech? One possible answer to this question is that the learner does not need to identify the predominant stress patterns because the tendency to segment fluent speech at strong syllables is universal and not dependent on experience with a particular language. Although this possibility cannot be entirely ruled out without data from infants exposed to languages other than English, it seems somewhat implausible given that stress placement on words differs considerably across the world's languages (Comrie, 1990). For example, in Polish, it is the penultimate syllable in a word that is usually stressed, whereas in French, the final syllable tends to be lengthened relative to other syllables. If all infants had a bias to segment words at strong syllables, infants learning Polish or French would have to overcome this bias to arrive at a correct word segmentation strategy for their native language. This does not mean that French or Polish learners do not use stress information in segmenting words from fluent speech. However, if they do use a stress-based strategy, it would have to be different in its particulars from the one that would be most useful to English learners. For example, French learners could possibly use information about lengthening at the ends of words as a marker of word offsets. Obviously, it would be interesting to have data on how learners of such languages begin to segment words from fluent speech.

Another possible explanation is that learners develop a bias for the predominant stress patterns of native language words on the basis of words that they hear frequently spoken in isolation. For example, names in English are most likely to begin with strong syllables, and those which do not often have nickname forms which do (Cutler, McQueen, & Robinson, 1990). English learners have been shown to have some ability to recognize the sound patterns of their own names by 4.5 months of age (Mandel, Jusczyk, & Pisoni, 1995). In addition, diminutive terms that are used frequently in addressing infants often have strong/weak stress patterns (e.g., ''mommy,'' ''daddy,'' ''baby,'' ''doggie,'' ''kitty,'' ''birdie,'' ''binky,'' etc.) If this account is correct, then in other languages, names and diminutives may also model the predominant word patterns.[4]

English-learning infants who segment speech at strong syllables will be successful in identifying many words, given the frequency of such words in conversational speech (Cutler & Carter, 1987). However, the onsets of words beginning with or consisting of weak syllables will be missed or misseg-

[4] This pattern does seem to hold for Swiss German (Penner, personal communication), for Japanese (Mazuka, personal communication), and for French (Legendre, personal communication).

mented. Thus, learners will have to rely on other kinds of indicators of potential word boundaries in order to correctly segment words from the speech stream. Other potential sources include context- or position-sensitive allophones (Church, 1987b; Gow & Gordon, 1995; Lehiste, 1960), phonotactic cues (Brent & Cartwright, 1996; Cairns et al., 1997), and distributional (or statistical) cues (Brent & Cartwright, 1996; Saffran et al., 1996b). None of these other cues is completely foolproof. Hence, it seems likely that mature English listeners rely on some combination of these potential cues to word boundaries in fluent speech. A number of infant language researchers have suggested that the integration of multiple sources of information for word boundaries is a necessary step in language acquisition (Morgan & Saffran, 1995; Myers et al., 1996). Moreover, a number of recent computational models of word segmentation have been shown to benefit from access to multiple sources of information about word boundaries (Brent & Cartwright, 1996; Cairns et al., 1997; Christiansen, Allen, & Seidenberg, 1997). On the basis of their model's performance, Christiansen et al. noted that the integration of the potential segmentation cues was greater than the sum of their individual contributions.

Of course, before learners can integrate different sources of information about potential word boundaries, they must develop some sensitivity to each of these sources. Saffran et al. (1996a; Aslin et al., 1998) have demonstrated that English-learning 8 month olds can use information about the frequency with which syllable sequences occur in the input to segment words from fluent speech. The present study provides additional evidence that such distributional cues do influence how 7.5 month olds segment potential words. A recent investigation by Mattys et al. (1999) provides evidence that 9-month-old English learners are sensitive to whether certain phonotactic sequences are more likely to be found within or between words. Knowledge of this distinction is a prerequisite for being able to use phonotactic cues in word segmentation. There are also indications that English-learning infants are developing sensitivity to allophonic cues to word boundaries between 9 and 10.5 months of age. Jusczyk et al. (in press) found that 10.5 month olds, but not 9 month olds, were able to use allophonic cues distinguishing ''nitrates'' from ''night rates'' to correctly segment these items in fluent speech. In the present study, 10.5 month olds were evidently able to use allophonic cues to correctly segment weak/strong words, such as ''guitar,'' out of the contexts in which they were always followed by the same weak syllable (i.e., ''guitar is'').

The picture that emerges from the present study is that learning to segment words is a gradual process. Infants' first attempts fall short of those of mature users of a language. One description of the way that word segmentation skills develop is ''divide and conquer'' (Jusczyk, 1998). Infants learning to segment words must begin by relying on some potential markers, and for English, breaking up fluent speech at strong syllable onsets is a reasonable place to start. Sensitivity to the occurrence of strong syllables in the speech stream provides the means for dividing longer utterances up into smaller chunks. These chunks often, but do not always, correspond to words in the language. Attention to sounds at the beginnings and ends of such chunks can in turn provide information about the positioning of allophones and phonotactic sequences within these chunks. As sensitivity develops to these properties, the learner can begin to integrate this information with other sources such as stress and distributional cues. There is evidence from several recent investigations that infants have some capacity to integrate multiple cues at around 9 months of age (Lalonde & Werker, 1995; Mattys et al., 1999; Morgan & Saffran, 1995).

One fruitful area for future research on the development of word segmentation skills is to investigate how infants cope with longer words in the language. Longer English words often include more than one strong syllable (e.g., ‘‘elephant,’’ ‘‘alligator,’’ ‘‘hippopotamus,’’ etc.) How do English learners segment items that include more than one strong syllable? Do they divide these words at strong syllable onsets or do they use distributional cues to keep the entire word intact? In addition, many questions arise regarding how infants integrate different cues to word boundaries. For example, are some cues more heavily weighted than others? When potential cues conflict, how do infants resolve the conflict? Are there changes during the course of development in the way that cues are integrated? One possibility is that infants' sensitivity to these different sources of information represents the development of something like a ‘‘Possible Word Constraint’’ (Norris, McQueen, Cutler, & Butterfield, 1997), whereby possible word parses are evaluated to determine whether they leave residues that are ill-formed words (e.g., single consonants).

Finally, it is worth noting that the present studies have focused on early word segmentation abilities of infants. In particular, we have examined when infants are able to respond to the sound patterns of words in fluent speech. We make no claims that infants at this age are following a conscious strategy to segment words from fluent speech. Indeed, the perceptual prominence of strong syllables may serve to draw their attention to these items. However, once they are drawn to such locations, the infants do seem to be responding to more than the vowel of these syllables because the consonantal onsets of these syllables does matter (Jusczyk & Aslin, 1995). We also are not suggesting that infants at this age know the meanings of the items with which they have been familiarized. Consequently, word segmentation abilities that infants are developing at this young age may change, or even regress, when they begin attending to meaning. Recent evidence suggests that infants' phonetic discrimination capacities are affected on tasks that require some attention to word meaning (Stager & Werker, 1997). Similarly, on tasks that demand explicit word recognition, the positioning of items within the sentence has been shown to affect infants' performance (Fernald, McRoberts, & Herrera, in press). Nevertheless, there is reason to believe that infants do extract and retain information about sound patterns of words from fluent speech even before they begin to attach specific meanings to these patterns. Jusczyk and Hohne (1997) found evidence that 8.5 month olds retained information about the sound patterns of frequently occurring words in stories over a 2-week interval. Thus, one aspect of building a lexicon may be to store information about the sound patterns of potential words. Furthermore, sensitivity to the occurrence and positioning of the sound patterns of words could also be useful in learning about the syntactic organization of one's native language. In this sense, the skills that infants are developing for word segmentation at this early age may be as important for the subsequent development of comprehension abilities as is babbling for the development of language production.

In conclusion, English-learning 7.5 month olds display some ability to segment words beginning with strong syllables from fluent speech. However, infants at this age appear to missegment words that begin with weak syllables. These findings suggest that English learners may initially identify strong syllables with the onsets of new words in fluent speech. By 10.5 months, English learners are able to segment words beginning with weak syllables from fluent speech, suggesting that they have learned to use other potential markers of word boundaries.

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Accepted March 3, 1999