Journal of Experimental Psychology:
Human Perception and Performance
2001, Vol. 27, No. 3, 644–655

0096-1523/01/$5.00 DOI: 10.1037//0096-1523.27.3.644

Do Infants Segment Words or Recurring Contiguous Patterns?

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Eight experiments tested the hypothesis that infants' word segmentation abilities are reducible to familiar sound-pattern parsing regardless of actual word boundaries. This hypothesis was disconfirmed in experiments using the headturn preference procedure: 8.5-month-olds did not mis-segment a consonant–vowel–consonant (CVC) word (e.g., *dice*) from passages containing the corresponding phonemic pattern across a word boundary (C#VC#; "cold ice"), but they segmented it when the word was really present ("roll dice"). However, they did not segment the real vowel–consonant (VC) word (*ice* in "cold ice") until 16 months. Yet, at that age, they still did not false alarm on the straddling CVC word. Thus, infants do not simply respond to recurring phonemic patterns. Instead, they are sensitive to both acoustic and allophonic cues to word boundaries. Moreover, there is a sizable developmental gap between consonant- and vowel-initial word segmentation.

For the young language learner, locating where words begin and end in the spoken input is a crucial step toward language acquisition. Not only do infants have to cope with the acoustic variability of words spoken in different contexts and by various talkers but they also must extract sound patterns (i.e., words) from a signal that contains few, if any, explicit and systematic word-boundary cues (Cole & Jakimik, 1980; Klatt, 1980; Liberman & Studdert-Kennedy, 1978; Woodward & Aslin, 1990). The process whereby infants handle the difficult task of segmenting words from fluent speech has only recently begun to be understood.

Evidence shows that infants' exposure to the ambient language during the first half of their 1st year of life allows them to notice regularities in the sound patterns of their language (see Jusczyk, 1997, for a review). Among the aspects of the sound organization that infants between 6 and 9 months old become sensitive to are properties that can potentially signal word boundaries in continuous speech. Drawing on multiple cues such as prosodic patterns (e.g., Echols, Crowhurst, & Childers, 1997; Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Houston, & Newsome, 1999; Mattys, Jusczyk, Luce, & Morgan, 1999; Morgan, 1996), phonotactic regularities (e.g., Friederici & Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Mattys & Jusczyk, 2001; Mattys et al., 1999), allophonic variations (e.g., Christophe, Dupoux, Bertoncini, & Mehler, 1994; Hohne & Jusczyk, 1994; Jusczyk, Hohne, & Bauman, 1999), and distributional probability (e.g., Goodsitt, Morgan, & Kuhl, 1993; Saffran, Aslin, & Newport, 1996), by the age of 7.5 months, infants can segment some words from fluent speech (Jusczyk & Aslin, 1995).

Many of the important findings about infant word segmentation have been obtained using a method based on the headturn preference procedure (HPP; Fernald, 1985; see Jusczyk, 1998). Typically, infants are familiarized to repetitions of isolated words (familiarization phase) and then presented with passages that do or do not contain the familiarized stimuli (testing phase)—but the opposite ordering of passages in familiarization and isolated words in testing has also been used (e.g., Jusczyk & Aslin, 1995; Jusczyk, Houston, et al., 1999; Mattys & Jusczyk, 2001). Longer listening times to passages containing the familiarized stimuli are interpreted as evidence that infants are able to extract the stimuli's sound patterns from the passages. To date, the vast majority of published studies on word segmentation by infants have used words as probes to examine infants' segmentation of speech. For instance, the studies try to determine whether infants detect the occurrence of *bike* in an utterance such as "Her bike could go very fast" (Jusczyk & Aslin, 1995). However, what infants are extracting from fluent speech is not entirely clear. Are they segmenting the word to which they were familiarized, or are they merely exhibiting sensitivity to a match between the familiarized target and a phonemic pattern that consistently recurs in the fluent speech, regardless of whether this pattern is a word? In other words, after being familiarized with the word *dice,* would infants show a preference for passages including sequences like "cold ice," "hard ice," "red ice," and so forth, which contain the target as a recurring pattern but not as a word?

The existing literature does not provide an answer to this question. On the one hand, recent studies indicate that infants are sensitive to slight acoustic or phonetic variations that tend to occur at syllable and word boundaries. For instance, Jusczyk, Hohne, et al. (1999) found that 10.5-month-olds can not only discriminate between similar-sounding sequences like "nitrates" and "night rates," but once familiarized with either "nitrates" or "night rates,"

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This work was supported by Research Grant 15795 from the National Institute of Child Health and Human Development and by Research Scientist Award 01490 from the National Institute of Mental Health. We thank Ann Marie Jusczyk and Elizabeth Johnson for comments on this article, Michael Brent and Daniel Swingley for each sharing his corpus data with us, and Katie Nuckel for performing acoustic analyses on our stimuli.

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they show a preference for a subsequent passage containing the appropriate allophonic version. This result suggests that when segmenting words from fluent speech, infants do more than simply pick up broad phonemic patterns that constitute acceptable matches with the familiarized target; they respond to the fine phonetic characteristics that correlate with word boundaries. Therefore, one would expect that infants in that age range should not respond to "cold ice" after familiarization to *dice*.

On the other hand, evidence also indicates that infants as young as 8 months exhibit some sensitivity to the statistical distribution of the information in the speech input. For instance, Saffran, Aslin, et al. (1996) found that 8-month-olds notice transitional probabilities between syllables in a continuous stream of speech and rely on these probabilities to parse subsequent test sequences. On the basis of this result, wherein infants used consistent co-occurrence patterns among syllables to segment a continuous speech stream, one might expect infants to behave similarly for consistent co-occurrence patterns among phonemes. If so, then the high transitional probability between the four phonemes of *dice* in passages containing "cold ice," "hard ice," "red ice," and so forth, would cause infants to mis-segment *dice* (i.e., erroneously spot it) from these lexically discrepant sequences. Consistent with this possibility, a recent study by Jusczyk, Houston, et al. (1999, Experiment 11) showed that 7.5-month-olds showed a preference for passages containing the recurrent sequence "guitar is" after being familiarized to the trochaic nonword *taris*. Thus, sometimes infants do seem to equate speech sequences whose word boundaries conflict regardless of the allophonic cues that could presumably reveal the mismatch. However, as Jusczyk, Houston, et al. noted, the mis-segmentation of *taris* from "guitar is" may have arisen from infants following a metrical segmentation strategy whereby parsing the input into strong–weak feet predominates over fine-grained word-boundary cues such as allophonic variations or phonotactic regularities (see also Mattys et al., 1999). In fact, 10.5-month-olds tested on the same materials did not show any indications of mis-segmentation, which is consistent with the notion that metrical segmentation becomes modulated by more subtle segmentation strategies as infants grow older, ultimately reaching more efficient adultlike parsing (Jusczyk, 1998).

The present investigation explores the possibility that just as young infants indiscriminately rely on a metrical segmentation strategy (Jusczyk, Houston, et al., 1999; Jusczyk, Brent, Nazzi, & Dahan, 2001; Mattys et al., 1999) so might they also extract consistently recurring sound patterns from fluent speech—whether these are real words or not.

Experiment 1

In this experiment, 8.5-month-olds were familiarized to repetitions of two words with a consonant–vowel–consonant (CVC) sound pattern produced in isolation (e.g., *dice* and *cash*). This familiarization phase was followed by the presentation of passages that either contained one of the familiarized patterns embedded across a word boundary (e.g., "The city truck cleare*d ice* and sand from the sidewalk" and "Builders sometimes pa*ck ash* in basements") or were made of words unrelated to the familiarized stimuli (e.g., "Today, we weed the shrub oats in our yard"). We used listening times to the two types of passages, obtained using the HPP of Kemler Nelson et al. (1995), as an index of the infants' detection of the familiarized stimuli in the passages. If 8.5-month-olds parse the input on the basis of the mere recurrence of phonemic patterns, they should show a listening preference for the passages that have the pattern of the target word embedded within them, even though this pattern does not correspond to a word. However, if infants are sensitive to word-boundary phonetic cues, they should reject the association between the target and a phonemic pattern that was not produced as a cohesive word. Hence, they should not show a preference for the passages containing the target word embedded across a word boundary.

Method

Participants. The participants were 24 infants (15 boys and 9 girls) from monolingual American-English-speaking homes, approximately 8.5 months old (M = 35 weeks, 5 days; range = 32 weeks, 6 days to 36 weeks, 6 days). Ten additional infants were tested, but their data were discarded from the analyses because the infants were restless (6), they cried (2), they did not look at the lights (1), or because the computer failed (1).

Stimulus materials. Four CVC words were chosen whose vowel–consonant (VC) portion also constituted a word: *dice* (ice), *cash* (ash), *boats* (oats), and *seal* (eel). Although *boats* is a consonant–vowel–consonant–consonant word, we refer to all targets as CVCs for simplicity. The CVC words were recorded in four separate lists. Each list contained 15 repetitions of one of the four words. Four six-sentence passages were also created. Each sentence in a given passage contained the sound pattern of one of the four target words embedded across a word boundary. That is, the target words (e.g., *dice*) were never present per se in the sentences, but their sound patterns (e.g., d#ice#, in which # represents a word boundary) emerged from a VC word preceded by an adequate word-final consonant (e.g., d#ice# in "cold ice" and "hard ice"). The position of the embedded string in the sentences varied from sentence to sentence (sentence initial, sentence medial, or sentence final). The four passages are listed in Appendix A. Acoustic measurements for the four lists of isolated words and for the four passages can be seen in Table 1. Amplitude was computed as the average decibel value of the entire CVC token and, separately, over the four periods in the middlemost section of the vowel (V)—a proxy for peak amplitude. Likewise, frequency was estimated as the average fundamental frequency (F0) (in hertz) across the entire CVC token and, separately, over the four middlemost periods of the V.

All of the speech samples were recorded with a Shure microphone in a sound-shielded booth by a woman who was a native speaker of American English. We encouraged the speaker to read the lists of isolated words and the passages in a lively voice, as if reading to a young child. Samples were digitized on a Computerized Speech Lab (CSL) 150 workstation at a 20-kHz sampling rate via a 16-bit analog-to-digital converter. Digitized versions of the samples were transferred to a Macintosh Quadra 650 computer for playback during the experiment. The average loudness level during playback, measured with a Quest (Model 215) sound level meter, was 71 ± 2 dB SPL.

Design. Half of the infants heard the *dice* and *cash* lists of isolated tokens during the familiarization phase, and the other half heard the *boats* and *seal* lists. During the test phase, all of the infants heard four blocks of the same four passages (d#ice#, c#ash#, b#oats#, s#eel#). Each block contained a different random ordering of the passages.

Apparatus. The Macintosh Quadra 650 controlled the presentation of the samples and recorded the observer's coding of the infant's response. The audio output for the experiment was generated from the digitized waveforms of the samples. A 16-bit digital-to-analog converter was used to recreate the audio signal. The output was fed through antialiasing filters and a Kenwood audio amplifier (KA 5700) to one of two Cambridge Soundworks loudspeakers mounted on the side walls of the testing booth.

The experiment was conducted in a three-sided test booth constructed out of 4- × 6-ft (1.2- × 1.8-m) pegboard panels. Except for a small section

Table 1
Acoustic Measurements for the Isolated Words of Experiments 1, 2, and 8, and for the Passages of Experiments 1, 3, 5, 6, 7, and 8

Word or passage	Duration: Total (s)	Duration: CVC (ms)	Duration: V (ms)	Amplitude (dB): CVC	Amplitude (dB): V	Frequency (Hz): CVC	Frequency (Hz): V
Isolated words							
dice	18.79	705	418	59	68	291	433
cash	18.89	784	408	59	68	286	449
boats	18.86	688	355	56	68	314	452
seal	18.44	678	294	59	67	262	355
M	18.74	714	369	58	68	288	422
Passages							
d#ice#	18.12	378	164	61	72	212	298
c#ash#	18.65	391	180	62	69	201	249
b#oats#	18.37	382	111	54	66	186	200
s#eel#	18.53	350	156	60	66	180	208
M	18.42	375	153	59	68	195	239

Note. For isolated words, Total is the duration of the total samples. Otherwise, all measurements are averaged across 15 tokens. For passages, Total is the duration of the entire passage. Otherwise, all measurements are averaged across six tokens. CVC = consonant–vowel–consonant word; V = vowel.

of preexisting holes in the center panel used for viewing the infant's head turns, the panels were backed with white cardboard to guard against the possibility that infants might respond to movements behind the panel. The test booth had a red light and a loudspeaker mounted at eye level on each side panel 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 that was suspended around the top of the booth shielded the infant's view of the rest of the room. A computer terminal and a 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 collected about the direction and duration of head turns for each trial was stored in a computer data file. Headturn Preference Procedure (Version 1.5) computer software (Sawusch, 1994) 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 lists were calculated by the computer after the completion of each session.

Procedure. A version of the HPP (Kemler Nelson et al., 1995) was used in the present experiment (see Jusczyk, 1998, for an extensive assessment of the method). 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 began with the flashing of the green light on the center panel. Once the infant had oriented in that direction, the light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a head turn of at least 30° in the direction of the loudspeaker, the stimuli for that trial began to play and continued until its completion or until the infant failed to maintain the 30° head turn for two consecutive seconds (e.g., the infant turned back to the center or to the other side; or looked at the caregiver, the floor, or the ceiling). If the infant turned briefly away from the target by 30° in any direction 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 speech 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 words on alternating trials until they accumulated 30 s of listening time to each one. If the infant achieved the familiarization criterion for one target but not for the other, the trials continued to alternate until the criterion was achieved for both. The side from which the lists of targets were played 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 trials for the test phase consisted of the four passages. Each infant was tested on four blocks of the four passages, for a total of 16 trials. The 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. Different random orders were used for each block.

An observer hidden behind the center panel looked through the peepholes and recorded the direction and duration of the infant's head turns using a response box. The observer was not informed as to which words served as familiarization for a given infant. In addition, both the observer and the infant's caregiver wore foam earplugs and listened to masking music over tight-fitting Peltor Aviation-7050 headphones. The masker consisted of loud instrumental music, which had been recorded with few silent periods. With such masking, caregivers and observers were made unable to determine the nature of the stimulus on the trial (see Kemler Nelson et al., 1995, for data on the efficacy of this masking procedure).

Results and Discussion

Mean listening times to the four passages (d#ice#, c#ash#, b#oats#, s#eel#) were calculated for each of the 24 infants. Listening times were then averaged for the passages containing the sound pattern of the familiarized words (henceforth "familiar" passages) and for the passages containing the sound pattern of the nonfamiliarized words ("unfamiliar" passages). Across all participants, the average listening times were 7.14 s (SD = 2.19) for the familiar passages and 6.80 s (SD = 2.52) for the unfamiliar passages. An analysis of variance (ANOVA) revealed that this difference was not significant, $F(1, 22) = 1.21$, $p = .28$.

This result indicates that 8.5-month-olds did not segment the familiarized words from subsequent speech passages despite the fact that the passages contained a phonemic match of these words. Thus, infants were apparently sensitive to word-boundary information occurring in the midst of the target patterns embedded in the passages; they did not segment a stimulus that was not a legitimate word. It could be argued that infants failed to notice the correspondence between the target words and the embedded patterns because of coarse durational differences between them. In particular, the duration of a word produced in isolation is typically longer than when it is produced in a fluent speech context. However, such differences were also present in earlier word-segmentation HPP studies (e.g., Jusczyk & Aslin, 1995; Jusczyk, Houston, et al., 1999; Mattys & Jusczyk, 2001), yet familiarity effects were observed for the words when they appeared in the test passages. Thus, the present result supports the hypothesis that in segmenting words from fluent speech, 8.5-month-old infants do more than just extract recurrent speech patterns from the input. They probably rely on the presence of other cues in the speech stream (Bolinger & Gerstman, 1957; Church, 1987; Umeda & Coker, 1974) to avoid mis-segmentation of the input based on simple phonemic equivalence (Christophe et al., 1994; Hohne & Jusczyk, 1994; Jusczyk, Hohne, et al., 1999). For example, the word-final /d/ that occurs in *cold* is, in general, only weakly released and may interact with a glottal stop if followed by a vowel-initial word, whereas the word-initial /d/ in *dice* is typically released. However, there is another possible interpretation of the present results. Perhaps infants at this age are simply unable to segment words such as *dice, boats, cash,* and *seal* from fluent speech contexts. This alternative strikes us as unlikely given Jusczyk and Aslin's (1995) finding that 7.5-month-olds could segment other monosyllabic words such as *cup* and *dog* from fluent speech. Nevertheless, it would be reassuring to have some indication that infants can actually segment the targets used in the present study. Therefore, we devised Experiment 2 to test 8.5-month-olds' ability to segment *dice, cash, boats,* and *seal* from passages containing these words as real lexical items.

Experiment 2

In this experiment, we investigated whether 8.5-month-old infants respond to recurring contiguous patterns when these patterns correspond to real words in the speech signal. Earlier evidence (e.g., Jusczyk & Aslin, 1995) suggests that infants as young as 7.5 months segment CVC words from fluent speech as well as bisyllabic strong–weak words (Jusczyk, Houston, et al., 1999). Consequently, we expect that 8.5-month-olds should also be able to segment our CVC words from passages containing them as real words.

Method

Participants. The participants were 24 infants (11 boys and 13 girls) from monolingual American-English-speaking homes, approximately 8.5 months old (M = 35 weeks, 5 days; range = 32 weeks, 2 days to 36 weeks, 6 days). Eight additional infants were tested, but their data were discarded from the analyses because the infants cried (5), they did not to look at the lights (1), or because the computer failed (2).

Stimulus materials. The passages used in Experiment 1 were rewritten such that they contained the target words as real words (see Appendix B). The new passages were matched with those of Experiment 1 in terms of numbers of words and syllables per sentence. Also, as before, the position of the target word was varied across sentences within a passage. The lists of isolated target words were those of Experiment 1 (*dice, cash, boats,* and *seal*). Acoustic measurements for the passages are displayed in Table 2. All new passages were recorded by the same speaker as in Experiment 1. The average loudness level of the passages was 71 ± 2 dB SPL.

Design. Half of the infants heard the *dice* and *cash* lists of isolated tokens during the familiarization phase, and the other half heard the *boats* and *seal* lists. During the test phase, all the infants heard four blocks of the same four passages, which included the target words *dice, cash, boats,* and *seal,* respectively. Each block contained a different random ordering of the passages.

Apparatus and procedure. These were the same as those used in Experiment 1.

Results and Discussion

Mean listening times to the four passages were calculated for each of the 24 infants. Listening times were then averaged for the passages containing the familiar words and for those containing the unfamiliar words. Across all participants, the average listening

Table 2
Acoustic Measurements for the Passages of Experiment 2

	Duration			Amplitude (dB)		Frequency (Hz)	
Passage	Total passage (s)	CVC (ms)	V (ms)	CVC	V	CVC	V
#dice#	18.68	407	203	62	74	217	239
#cash#	18.71	404	181	61	69	203	248
#boats#	18.78	388	124	56	70	168	192
#seal#	18.21	396	120	60	70	250	284
M	18.59	399	157	60	71	209	241

Note. Except for the duration of the passages, all measurements are averaged across six tokens. CVC = consonant–vowel–consonant word; V = vowel.

times were 7.24 s ($SD = 2.15$) for the familiar passages and 6.00 s ($SD = 1.82$) for the unfamiliar passages. An ANOVA indicated that this difference was significant, $F(1, 22) = 6.79$, $p < .02$.

This result confirms the view that 8.5-month-olds are capable of segmenting CVC words from fluent speech (Jusczyk & Aslin, 1995). Moreover, the significant listening time difference obtained with the present set of words supports the hypothesis that the null result of Experiment 1 arose because infants did not false alarm on phonemic patterns straddling word boundaries, not because the target words were intrinsically hard to parse.

Thus, taken together, Experiments 1 and 2 suggest that a good predictor of infants' segmentation of sound patterns from fluent speech is whether the sound patterns are realized as real words in the connected speech samples. In the above experiments, infants responded to words but not to recurring patterns of contiguous phonemes. Tables 1 and 2 show that the coarse acoustic specifications of the target patterns were not significantly different in the passages containing them across a word boundary (Experiment 1) and in those containing them as real words (Experiment 2); CVC duration, $t(1, 23) = -0.71$, $p = .48$; V duration, $t(1, 23) = -0.39$, $p = .70$; CVC amplitude, $t(1, 23) = -0.63$, $p = .53$; V amplitude, $t(1, 23) = -1.59$, $p = .18$; CVC frequency, $t(1, 23) = -0.87$, $p = .39$; V frequency, $t(1, 23) = -0.11$, $p = .91$. Therefore, it is more likely that the different response patterns that infants show in extracting familiarized sequences from the passages used in the two experiments are not attributable to gross acoustic mismatches in the target patterns of the passages in each experiment.

Another possibility is that, despite their relative acoustic equivalence, the target words could have been preceded by words differing in their degree of acoustic salience. In particular, a highly stressed word prior to the target could have generated some forward acoustic or attentional masking of the target itself, and such masking might have been greater in the C#VC# (Experiment 1) than the #CVC# (Experiment 2) passages. To test this hypothesis, we measured the peak amplitude and peak frequency of the word preceding the target word in each sentence of the C#VC# and the #CVC# passages and compared these with the peak amplitude and frequency of the target words. The average amplitude and frequency of the pretarget words were 70 dB and 276 Hz in the C#VC# passages and 68 dB and 256 Hz in the #CVC# passages. An ANOVA factoring Amplitude × Type of Words (pretarget vs. target) × Experiment (C#VC# vs. #CVC# passages) did not reveal any significant main effects: type of words, $F(1, 23) < 1$; Experiment, $F(1, 23) < 1$; or interaction, $F(1, 23) = 2.93$, $p = .10$. Similarly, an ANOVA performed on the frequency of the pretarget and target words showed no significant main effects: type of words, $F(1, 23) = 1.66$, $p = .21$; Experiment, $F(1, 23) < 1$; or interaction, $F(1, 23) < 1$. Thus, overall, there was no evidence that the degree of stress in the word preceding the target could have prevented the detection of the target in one experiment more than in the other. Consequently, our results are best explained by the hypothesis that infants are responding to more subtle cues, such as the kinds of allophonic markers that occur in the vicinity of word boundaries (Church, 1987; Hohne & Jusczyk, 1994; Jusczyk, Hohne, et al., 1999; Lehiste, 1960).

Experiment 3

The pattern of results in Experiments 1 and 2 indicates that infants need to hear the lexical version of a word target (#CVC#), as opposed to a boundary-straddling phonemic match (C#VC#), to segment that word from fluent speech. One possible explanation for these results is that the infants are actually segmenting the real VC word contained in the C#VC# sequences (e.g., *ice* in "cold ice"). Given that infants at this age can segment monosyllabic CVC targets from fluent speech, it seems reasonable to suppose that they will fare well with VC targets, too. To explore this possibility, 8.5-month-olds were familiarized with either the words *ice* and *ash* or *oats* and *eel* and then tested on the d#ice#, c#ash#, b#oats#, and s#eel# passages of Experiment 1.

Method

Participants. The participants were 24 infants (9 boys and 15 girls) from monolingual American-English-speaking homes, approximately 8.5 months old ($M = 35$ weeks, 6 days; range = 34 weeks, 5 days to 37 weeks, 3 days). Four additional infants were tested, but their data were discarded from the analyses because the infants were restless (2) or they cried (2).

Stimulus materials. The passages were the d#ice#, c#ash#, b#oats#, and s#eel# passages of Experiment 1. Four new lists of isolated target words were recorded. Each list contained one of the four VC words (*ice, ash, oats,* and *eel*) repeated 15 times. Acoustic measurements for the lists of isolated words are shown in Table 3. All lists were recorded by the same speaker as in Experiment 1. The average loudness of the lists was 71 ± 2 dB SPL.

Design. Half of the infants heard the *ice* and *ash* lists of isolated tokens during the familiarization phase, and the other half heard the *oats* and *eel*

Table 3
Acoustic Measurements for the Isolated Words of Experiments 3, 5, 6, and 7

	Duration			Amplitude (dB)		Frequency (Hz)	
Word	Total sample (s)	VC (ms)	V (ms)	VC	V	VC	V
ice	16.90	623	407	62	71	391	511
ash	16.30	645	369	59	68	338	480
oats	16.62	679	380	56	67	307	413
eel	15.94	553	458	61	68	308	418
M	16.44	625	403	59	68	336	455

Note. Except for the duration of the total samples, all measurements are averaged across 15 tokens. VC = vowel–consonant word; V = vowel.

lists. During the test phase, all of the infants heard four blocks of the same four passages (d#ice#, c#ash#, b#oats#, s#eel#). Each block contained a different random ordering of the passages.

Apparatus and procedure. These were the same as those used in Experiment 1.

Results and Discussion

Mean listening times to the four passages (d#ice#, c#ash#, b#oats#, s#eel#) were calculated for each of the 24 infants and then averaged for the passages containing the familiar words and for those containing the unfamiliar words. Across all participants, the average listening times were 6.50 s ($SD = 2.82$) for the familiar passages and 6.48 s ($SD = 2.21$) for the unfamiliar passages. This difference was not statistically significant, $F(1, 22) < 1$.

Contrary to our expectations, infants did not segment the VC words from the passages, even though these were produced as real lexical items. This result is in contrast with studies showing that infants between 7.5 and 8.5 months can recognize monosyllabic words from fluent speech (Jusczyk & Aslin, 1995; Mattys & Jusczyk, 2001). One possible explanation for infants' failure to segment the VC words is that the systematic co-occurrence of a particular consonant before the target word (e.g., *d* in "cold ice" and "hard ice") may have interfered with the extraction process. Indeed, as Brent and Cartwright's (1996) computational Incremental Distributional Regularity Optimization (INCDROP) model suggests and data from Saffran, Aslin, et al. (1996) and Saffran, Newport, and Aslin (1996) illustrate, high transitional probability between speech segments tends to promote cohesion in the percept, whereas low probability helps signal a word boundary. Thus, it is possible that the co-occurrence of a fixed consonant and the following VC word was not strong enough to generate missegmentation of a boundary-straddling pattern (Experiment 1), but it generated enough cohesion to prevent the extraction of the VC word (Experiment 3). If this hypothesis is correct, then removing the co-occurrence of the consonant and the following VC word should allow the extraction of the VC target.

Experiment 4

In this experiment, infants were familiarized to two of the VC words and then tested on #ice#, #ash#, #oats#, and #eel# passages without potentially misleading contextual cues. That is, the passages were rewritten such that the word preceding the VC target ended with a consonant that varied from sentence to sentence. If 8.5-month-olds are able to segment VC words from fluent speech when the VC targets are freed from co-occurring phonemes, then they should show a preference for the passages containing the familiarized VC words.

Method

Participants. The participants were 24 infants (13 boys and 11 girls) from monolingual American-English-speaking homes, approximately 8.5 months old (M = 36 weeks, 5 days; range = 34 weeks, 2 days to 39 weeks, 1 day). Five additional infants were tested, but their data were discarded from the analyses because the infants were restless (1), they cried (1), they did not look at the lights (1), they did not look to each side for an average of 3 s (1), or because the computer failed (1).

Stimulus materials. As in Experiment 3, each list of isolated target words contained one of the four VC words (*ice, ash, oats,* and *eel*) repeated 15 times. The new passages were identical to those of Experiment 3 except that the word preceding the target VC word was replaced with one that ended with a different consonant in each sentence (see Appendix C). Both the lists of isolated words and the passages were recorded by another woman who was also a native speaker of American English. Acoustic measurements for the lists of isolated words and for the passages can be seen in Table 4. The average loudness of the samples was 71 ± 2 dB SPL.

Design. Half of the infants heard the *ash* and *ice* lists of isolated tokens during the familiarization phase, and the other half heard the *oats* and *eel* lists. During the test phase, all of the infants heard four blocks of the same

Table 4
Acoustic Measurements for the Isolated Words and for the Passages of Experiment 4

	Duration			Amplitude (dB)		Frequency (Hz)	
Word or passage	Total (s)	VC (ms)	V (ms)	VC	V	VC	V
			Isolated words				
ice	17.98	586	310	57	65	317	320
ash	17.75	624	336	56	62	317	316
oats	18.19	624	274	53	65	298	298
eel	18.24	541	300	61	65	304	314
M	18.04	594	305	57	64	309	312
			Passages				
#ice#	18.12	324	174	54	58	205	206
#ash#	18.68	362	210	56	58	195	195
#oats#	16.69	319	127	51	59	188	188
#eel#	17.71	223	128	60	61	192	203
M	17.80	307	160	55	59	195	198

Note. For isolated words, Total is the duration of the total samples. Otherwise, all measurements are averaged across 15 tokens. For passages, Total is the duration of the entire passage. Otherwise, all measurements are averaged across six tokens. VC = vowel–consonant word; V = vowel.

four passages, which included the target words *ice, ash, oats,* and *eel,* respectively. Each block contained a different random ordering of the passages.

Apparatus and procedure. These were the same as those used in Experiment 1.

Results and Discussion

Mean listening times to the four passages were calculated for each of the 24 infants and then averaged for the passages containing the familiar words and for those containing the unfamiliar words. Across all participants, the average listening times were 6.48 s (SD = 1.98) for the familiar passages and 6.10 s (SD = 2.22) for the unfamiliar passages. An ANOVA revealed that this difference was not statistically significant, $F(1, 22) < 1$.

Thus, infants did not segment the VC targets from the passages even when there was no systematic co-occurrence between the VC target and the preceding consonant. Moreover, an ANOVA combining the data from Experiments 3 and 4 did not show any main effect of familiarity, $F(1, 44) < 1$; preceding context (i.e., Experiment 3 vs. Experiment 4), $F(1, 44) < 1$; or interaction between familiarity and preceding context, $F(1, 44) < 1$. This indicates that whether the phoneme preceding the target word was fixed or varied freely, infants did not show any evidence that they were able, at 8.5 months, to segment VC words from fluent speech.

One major difference between this experiment and studies that have reported successful segmentation of monosyllables between 7.5 and 9 months of age (Jusczyk & Aslin, 1995; Mattys & Jusczyk, 2001) is that the present target words had a vocalic onset, whereas the other studies (and Experiment 2) dealt with consonant-initial words. Therefore, our data suggest that vowel-initial words are more difficult to extract from fluent speech than are consonant-initial words. There could be at least two reasons for this. First, vowel-onset words are at a disadvantage from a distributional point of view: There are far more consonant-onset words in the lexicon than there are vowel-onset words, both in infant- and adult-directed speech. For instance, Swingley's (1999) analysis of a child-directed input corpus indicated that only 19% of the tokens were vowel-initial words. The independent analysis of another corpus of infant-directed speech (Brent & Siskind, in press) revealed a very similar 20% of vowel-initial words. In much the same way, van de Weijer (1998) reported that only about 15% of all words addressed to a 6-month-old Dutch infant are vowel-initial words. Thus, it is plausible that because of the relatively low exposure to vowel-initial words, infants' detection of such words in their linguistic environment could be impaired or delayed. However, it seems unlikely that experience with the particular test words used in the present study could have been a critical factor in the differential response patterns to CVC and VC words. Inspection of child-directed speech in the Bernstein (1982) corpus from the CHILDES database suggests that all of our test words are extremely infrequent in the infant–child linguistic environment (0 in CHILDES), with the exception of *ice,* which occurred six times. Thus, if the difference between zero and six occurrences were considered meaningful, such a difference would presumably be in favor of VCs' being extracted, not CVCs.

Another reason that infants have difficulty segmenting vowel-initial words could be that the onsets of such items in continuous speech are acoustically not as prominent and well defined in time as are the onsets of consonant-initial words (Olive, Greenwood, & Coleman, 1993; Stevens, 1998). In fact, the very choice of consonant-initial words in studies of word segmentation in infants has often been motivated by these words' relatively clear-cut and stable (i.e., qualitatively unaffected by the syllable's stress degree) onsets across tokens (see, e.g., Jusczyk & Aslin, 1995, p. 5).

Regardless of the exact cause of 8.5-month-olds' inability to segment vowel-onset words from fluent speech, the results of Experiments 3 and 4 enjoin us to interpret the null result of Experiment 1 with some caution. In Experiment 1, we found that infants did not mis-segment a recurrent sound pattern from fluent speech when that pattern straddled a word boundary (e.g., *dice* in "cold ice"). However, whereas Experiment 2 confirmed that infants could segment the same CVC target when it appeared as a real word in the passage (#CVC#), Experiments 3 and 4 showed that they did not segment the legitimate word (e.g., *ice*) in the C#VC# passages. A more effective rebuttal of the claim that infants are only extracting recurring contiguous patterns from continuous speech would be to show that even when infants can extract words with vocalic onsets, they still do not mis-segment the C#VC# patterns. Consequently, in the next experiments, we tried to establish the age at which infants are capable of extracting vowel-initial words.

Experiment 5

Experiment 5 was identical to Experiment 3, in which infants were familiarized to VC words (e.g., *ice*) and then tested on passages containing these target stimuli as real vowel-initial words (e.g., d#ice#). However, in this experiment, the infants were 10.5 months old.

Method

Participants. The participants were 24 infants (10 boys and 14 girls) from monolingual American-English-speaking homes, approximately 10.5 months old (M = 45 weeks, 1 day; range = 41 weeks, 3 days to 48 weeks, 5 days). Three additional infants were tested, but their data were discarded from the analyses because the infants did not look at the lights (1) or because the computer failed (2).

Stimuli, design, apparatus, and procedure. These were the same as those used in Experiment 3.

Results and Discussion

Mean listening times to the four passages (d#ice#, c#ash#, b#oats#, s#eel#) were calculated for each of the 24 infants. Listening times were then averaged for the passages containing the familiar words and for those containing the unfamiliar words. Across all participants, the average listening times were 6.58 s (SD = 1.84) for the familiar passages and 6.42 s (SD = 2.16) for the unfamiliar passages. This difference was not statistically significant, $F(1, 22) < 1$.

This result suggests that 10.5-month-olds, like 8.5-month-olds, are unable to segment monosyllables with a vocalic onset from fluent speech. Continuing the logic of pinpointing the onset age of vowel-initial word extraction, we conducted the same experiment with 13-month-old infants.

Experiment 6

Method

Participants. The participants were 24 infants (10 boys and 14 girls) from monolingual American-English-speaking homes, approximately 13 months old (M = 56 weeks, 6 days; range = 55 weeks, 6 days to 59 weeks). Four additional infants were tested, but their data were discarded from the analyses because the infants were restless (1), they cried (1), they did not look at the lights (1), or they did not look to each side for an average of 3 s (1).

Stimuli, design, apparatus, and procedure. These were the same as those used in Experiment 3.

Results and Discussion

Mean listening times to the four passages were calculated for each of the 24 infants and then averaged for the passages containing the familiar words and for the ones containing the unfamiliar words. The average listening times were 6.88 s (SD = 3.08) for the familiar passages and 7.33 s (SD = 3.02) for the unfamiliar passages. Once again, this difference was not statistically significant, $F(1, 22) < 1$. Therefore, we decided to continue our exploration of vowel-onset word segmentation with 16-month-old participants.

Experiment 7

Method

Participants. The participants were 24 infants (12 boys and 12 girls) from monolingual American-English-speaking homes, approximately 16 months old (M = 68 weeks, 5 days; range = 67 weeks to 70 weeks, 1 day). Seven additional infants were tested, but their data were discarded from the analyses because the infants were restless (1), they cried (2), they did not look at the lights (3), or because the computer failed (1).

Stimuli, design, apparatus, and procedure. These were the same as those used in Experiment 3.

Results and Discussion

Mean listening times to the four passages were calculated for each of the 24 infants and then averaged for the passages containing the familiar words and for those containing the unfamiliar words. The average listening times were 7.20 s (SD = 2.56) for the familiar passages and 6.09 s (SD = 3.04) for the unfamiliar passages. An ANOVA revealed that this difference was statistically reliable, $F(1, 22) = 6.24$, $p = .02$. To further evaluate the apparent developmental trend in segmenting vowel-initial words, we analyzed the data from Experiments 3, 5, 6, and 7 in an omnibus ANOVA. Overall listening times did not significantly differ from each other across experiments, $F(3, 88) < 1$. The main familiarity effect was not reliable, $F(1, 88) < 1$. However, as expected, there was a significant interaction between experiment and familiarity, $F(3, 88) = 2.77$, $p < .05$, attributable to the fact that only 16-month-olds gave evidence of segmenting the vowel-initial targets from the passages.

The result of this experiment, in conjunction with the results obtained in the previous experiments, indicates that the parsing of vowel-initial words is considerably delayed compared with that of consonant-initial words. Whereas efficient extraction of consonant-initial words was observed as early as 8.5 months in Experiment 2 (e.g., *dice*) and 7.5 months in an earlier investigation (Jusczyk & Aslin, 1995), comparable findings for vowel-initial words are not apparent until 16 months.

The substantial lag between the extraction of consonant- and vowel-initial words, though intriguing, is not at odds with the available literature. For example, Nazzi, Jusczyk, and Bhagirath (1999) observed that segmentation of iambic vowel-initial verbs (e.g., *incites* and *imports*) was delayed relative to that of consonant-initial verbs (e.g., *discounts* and *permits*). Evidence for the former did not occur until 16 months, compared with 13.5 months for the consonant-initial stimuli. Even though the stimuli in the Nazzi et al. study differed from ours in length and stress pattern, Nazzi et al.'s results clearly confirm that the delay between consonant- and vowel-initial word extraction extends beyond our own stimuli and design. In addition, as suggested earlier, such a differential time course is also supported by distributional and acoustic data on vowel-initial words.

After determining that 16-month-olds segment vowel-initial words from fluent speech, we returned to our initial concern. Given that 16-month-olds can extract VC words from the speech signal, will they be misled into responding to a recurring C#VC# phonemic pattern when familiarized with a CVC word? In other words, does the facility in segmenting both consonant- and vowel-onset words also bring with it the tendency to segment any co-occurring sequences from fluent speech, regardless of whether these sequences violate word boundaries? Or do 16-month-olds display sensitivity to the real word boundaries in the input?

Experiment 8

In this experiment, we tested 16-month-olds on a replication of Experiment 1. The infants were familiarized with CVC words (e.g., *dice*). These CVC sequences were, subsequently, present in the test passages but straddled a word boundary (e.g., "cold ice" and "hard ice"). If, on the one hand, infants' word-segmentation strategies involve mere phonemic pattern mapping, we should find a familiarity effect for the passages containing the target word across a boundary. On the other hand, if segmentation strategies take into account word-boundary cues such as allophonic variations, infants should not false alarm on the passages containing a nonlexical version of the target.

Method

Participants. The participants were 24 infants (12 boys and 12 girls) from monolingual American-English-speaking homes, approximately 16 months old (M = 69 weeks; range = 67 weeks, 3 days to 71 weeks, 3 days). Six additional infants were tested, but their data were discarded from the analyses because they were restless (2), they cried (2), or they did not look to each side for an average of 3 s (2).

Stimuli, design, apparatus, and procedure. These were the same as those used in Experiment 1.

Results and Discussion

Mean listening times to the four passages were calculated for each of the 24 infants and averaged for the passages containing the familiar words and for those containing the unfamiliar words. The average listening times were 7.47 s (SD = 3.22) for the familiar passages and 7.38 s (SD = 2.55) for the unfamiliar passages. An

ANOVA revealed that this difference was not statistically reliable, $F(1, 22) < 1$. Consequently, familiarization to CVC target words did not cause the infants to listen significantly longer to passages containing the sound patterns of the targets across a word boundary than to unrelated passages.

This result replicates the original result of Experiment 1 and confirms that early segmentation strategies are more than a simple phonemic match between a familiarized pattern and the recurrence of that pattern in connected speech. Apparently, infants are sensitive to subphonemic or suprasegmental information, or both, that prevents them from mis-segmenting the input.

General Discussion

A considerable amount of research has been conducted since Jusczyk and Aslin (1995) showed that English-learning 7.5-month-olds can segment words from continuous speech. Many studies have demonstrated that in the second half of their 1st year, infants are able to exploit a wide variety of word-boundary cues to some degree in segmenting words. Although we still lack a complete picture of how these different sources of information are integrated, English learners display sensitivity to different types of cues at different ages. Thus, although sensitivity to prosodic cues has been observed at 7.5 months (Jusczyk, Houston, et al., 1999) and sensitivity to distributional cues at 8 months (Saffran, Aslin, et al., 1996), sensitivity to phonotactic cues (Mattys et al., 1999) and to allophonic cues (Jusczyk, Hohne, et al., 1999) has not been reported until 9 and 10.5 months, respectively. Moreover, recent research also indicates that not all these cues are equal, either in the frequency with which they appear or in the degree of their reliability. This observation has led to investigations in which segmentation cues were evaluated not individually but relative to one another (Christiansen, Allen, & Seidenberg, 1998; Johnson & Jusczyk, in press; Jusczyk et al., 2001; Mattys et al., 1999; Morgan & Saffran, 1995). Thus, word-boundary cues appear to be hierarchically organized, with some reorganization of the hierarchy likely occurring in the course of development. For example, metrical segmentation (e.g., Cutler & Butterfield, 1992; Cutler & Norris, 1988), in which strong syllables are de facto given a word-onset status, is clearly dominant in early infancy (Johnson & Jusczyk, in press; Jusczyk, Houston, et al., 1999; Mattys et al., 1999; Morgan & Saffran, 1995). However, around 10.5 months, cases of erroneous metrical segmentation (on noninitial-stress words) become scarce, presumably being replaced by more complex algorithms (Jusczyk, 1999; Jusczyk, Houston, et al., 1999).

Despite the evidence that infants may rely heavily on particular types of segmentation cues before 10.5 months (e.g., prosodic stress), the present study shows that the general mechanism responsible for spotting familiarized words in continuous speech is already quite sophisticated at 8.5 months. The experiments reported above demonstrate that neither 8.5-month-olds nor 16-month-olds segment fluent speech by simply extracting recurring patterns of contiguous phonemes. That is, neither age group showed evidence of mis-segmenting *dice* from "The city truck cleared ice and sand from the sidewalk," even though the word was present in a phonemic form. In contrast, infants could easily pick up the same word in "Many dealers throw dice with one hand." Thus, even though infants may use information about distributional probabilities in segmenting words (Saffran, Aslin, et al., 1996), sensitivity to statistical information does not preclude the use of other types of boundary cues. Had infants strictly relied on the recurrent distribution of contiguous sounds in the passages, they should have extracted *dice* from both samples (see also Johnson & Jusczyk, in press).

What keeps infants from segmenting *dice* from a sequence like "cold ice"? The most plausible explanation is that infants respond to certain speech properties associated with the presence of a word boundary. The allophonic cues that potentially differentiated the within- and between-word versions of our stimuli can be found in both the first consonant and the vowel of the #CVC# and C#VC# strings. For instance, /k/ is usually aspirated when it begins a word in English (e.g., /k/ in "cash") whereas it is not in other positions (e.g., /k/ in "dark ash"). Noticing this distinction could have encouraged the listeners to hear the target word *cash* in the string /kʰæʃ/ but not in the across-word string /kæʃ/. Phonetic realization of vowels, too, greatly differs with their position in words: Vowels are more likely to be glottalized—their onsets display pitch periods irregular in timing or shape—at the beginning of words than in other positions (e.g., Allen, 1970; Gimson, 1980; Umeda, 1978). Consequently, the perception of a glottal gesture (as in /dʔɑɪs/) would signal the onset of a vowel-initial word, leading listeners away from perceiving the sequence as the familiarized target word (e.g., *dice* /dɑɪs/). Thus, what probably influenced word extraction in our experiments are acoustic cues indicating whether tokens were produced as cohesive speech units, over and above mere phonemic wellformedness.

The other noticeable finding in the present study is that infants have considerably more difficulty segmenting vowel-initial than consonant-initial words from fluent speech. Experiments 3–7 showed that infants failed to segment VC words (e.g., *ice*) until 16 months of age. This result, together with data found by Nazzi et al. (1999) showing that the segmentation of vowel-initial verbs and that of consonant-initial verbs are also offset by a few months, supports the growing evidence that infants' segmentation abilities undergo important maturation after 7.5 months. For example, it is not until 10.5 months that infants learn to segment weak–strong words from passages (Jusczyk, Houston, et al., 1999) and to generalize their word-segmentation ability across speakers of different genders (Houston & Jusczyk, 2000). Our experiments suggest that the segmentation of vowel-initial words is another ability whose development is considerably delayed.

As pointed out earlier, the developmental gap between the two types of words might arise from the relative rarity of vowel-initial words in ambient speech. Previous research has shown convincingly that both infants and adults are sensitive to distributional factors in their linguistic environment (e.g., Cutler & Carter, 1987; Davis & Kelly, 1997; Jusczyk, Cutler, et al., 1993; Jusczyk et al., 1994; Kelly & Martin, 1994; Mattys et al., 1999). For example, the predominance of stress-initial words in the English lexicon is the basis for the metrical segmentation of speech (Cutler & Carter, 1987; Cutler & Norris, 1988; Jusczyk et al., 1993). Correspondingly, the relative infrequence of noninitial-stress content words seems to be a factor in the developmental delay in segmenting such words from fluent speech (Jusczyk, Houston, et al., 1999) and the source of various mis-segmentation phenomena at the adult stage (e.g., Cutler & Butterfield, 1992; Mattys & Samuel, 2000). Therefore, in much the same way, the low-frequency occurrence of words with a vocalic onset could be the cause of the developmental lag observed in our results.

The lack of clearly demarcated acoustic cues in vowels is also a likely factor. Whereas consonants—especially plosives—have a well-defined onset often accompanied with a short and distinctive burst, vowels tend to be smeared at onset and offset because of coarticulation. If the absence of clear temporal boundaries is responsible for the vowel-initial word segmentation lag, then we predict that glides and liquids, which have less precise boundaries than stop consonants, should also cause the segmentation of words beginning with such sounds to be delayed. Future studies could test this hypothesis by (a) having an equal number of target words beginning with a plosive and with a glide and (b) controlling the phonemic environment of both conditions (e.g., two *lean/keen* athletes).

In conclusion, the present findings add to our understanding of the development of word-segmentation abilities in two ways. First, they provide evidence that infants do not simply extract any sound patterns that recur frequently in fluent speech. Instead, even 8.5-month-olds give some evidence of sensitivity to word boundaries in extracting patterns of potential words from fluent speech contexts. Notably, they do not match a familiarized sound pattern to a corresponding phonemic sequence straddling a word boundary. Second, the present results also reveal that young infants' abilities to segment words depend importantly on the phonemic make-up of words. Specifically, English-learning infants are considerably delayed in their ability to segment words with vocalic onsets relative to their ability to segment words with consonant onsets (e.g., Jusczyk & Aslin, 1995; Jusczyk, Hohne, et al., 1999; Jusczyk, Houston, et al., 1999; Mattys & Jusczyk, 2001; Saffran, Aslin, et al., 1996). Hence, it is increasingly apparent that although word-segmentation capacities begin at a relatively early age (around 7.5 months), the full development of these capacities is a gradual process extending well into the 2nd year. Indeed, given the important role of lexical competition in most models of adult word recognition (e.g., Luce & Pisoni, 1998; McClelland & Elman, 1986; Norris, 1994; Norris, McQueen, & Cutler, 1995; Vitevitch & Luce, 1999), it seems likely that further refinements of word-segmentation abilities will occur as the lexicon develops.

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Appendix A

Passages Used in Experiments 1, 3, 5, 6, 7, and 8

d#ice#
Weird ice no longer surprises anyone.
The experts soon detected that it was flawed ice.
The city truck cleared ice and sand from the sidewalk.
The rink had been sprinkled with spread ice.
Fluid ice is a difficult concept to grasp.
Merchants used to trade ice for water.

c#ash#
Dark ash comes from strong old trees.
Sooner or later, everyone will begin to like ash.
In a fireplace, nobody likes to see fake ash.
Builders sometimes pack ash in basements.
The worker took ash and sand from the cave.
Pink ash is becoming difficult to find.

b#oats#
Crib oats were rather mysterious until recently.
People thought they were similar to scab oats.
The cheapest kind was called club oats.
Knob oats were used to make the cereal.
Today we weed the shrub oats in our yard.
Jack was told not to plant web oats.

s#eel#
The nice eel was put on display for months.
But people preferred the famous space eel.
Very soon it would be a loose eel again.
Sophia found a brass eel in an antique shop.
This eel was more expensive than she thought.
It was lying next to a coarse eel.

Appendix B

Passages Used in Experiment 2

#dice#
Two dice can be rolled without difficulty.
Many dealers throw dice with one hand.
Four dice are much harder to roll with precision.
Some people make a living throwing dice.
Playing with blue dice is common for beginners.
French casinos often store many dice.

#cash#
To cash a check is becoming more easy.
It is better to have two cash machines nearby.
Stolen money is referred to as filthy cash.
The cash flow concept is taught in schools.
Many workers may cash their checks on Sunday.
Frequent thefts have forced banks to dye cash.

#boats#
Many boats transport cargo across oceans.
Very few boats carry passengers in winter.
Going back and forth would require two boats.
Small boats can sometimes go faster than big ones.
Some ferry companies own blue boats.
In the port, fifty boats are ready to unload.

#seal#
A gray seal is a beautiful animal.
It is known for its pricey seal oil.
Catching a seal in the winter is rare.
It is even harder to find a blue seal.
The seal can survive in very cold temperatures.
I like my seal better than any others.

Appendix C

Passages Used in Experiment 4

#ice#
Weird ice no longer surprises anyone.
The experts soon detected that it was fake ice.
The city truck left ice and sand on the sidewalk.
The rink had been sprinkled with some ice.
Fool ice is a difficult concept to grasp.
Merchants used to give ice for water.

#ash#
Dark ash comes from strong old trees.
Sooner or later, everyone will begin to keep ash.
In a fireplace, nobody likes to see white ash.
Builders sometimes store ash in basements.
The worker dug ash and sand from the cave.
Wood ash is becoming difficult to find.

#oats#
Crib oats were rather mysterious until recently.
People thought they were similar to wheel oats.
The cheapest kind was called mock oats.
Deep oats were used to make the cereal.
Today we weed the smooth oats in our yard.
Jack was told not to plant clog oats.

#eel#
The nice eel was put on display for months.
But people preferred the famous cat eel.
Very soon it would be a swamp eel again.
Sophia found a big eel in an antique shop.
That eel was more expensive than she thought.
It was lying next to a stone eel.

Received April 3, 2000
Revision received September 6, 2000
Accepted September 15, 2000 ■