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Segmentation of vowel-initial words is facilitated by function words

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ABSTRACT OF THE THESIS

Segmentation of vowel-initial words is facilitated by function words

By

Yun Jung Kim

Master of Arts in Linguistics

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Professor Megha Sundara, Chair

Within the first year of life, infants learn to segment words from fluent speech. Previous research has shown that 7.5-month-olds can segment consonant-initial words, yet the ability to segment vowel-initial words does not emerge until 13.5-16 months of age (11-months in some restricted cases). In Experiment 1, we test 8- and 11-month-olds' ability to segment vowel-initial words that immediately follow the frequently occurring function word *the*. In two subsequent experiments we rule out the role of bottom-up cues such as phonotactics or allophonic variations in explaining these results. Our results indicate that the function word *the* facilitates 11-month-olds' segmentation of vowel-initial words that appear sentence-medially.

The thesis of Yun Jung Kim is approved.

Robert Daland

Nina Hyams

Megha Sundara, Committee Chair

University of California, Los Angeles

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1. Introduction

According to the lexical norms of the MacArthur-Bates Communicative Development Inventories (CDI; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994), 11-month-old infants can comprehend several vowel-initial words, such as body parts (*arm, ear, eye*) and the verb *eat*. However, studies on word segmentation report that the ability to segment vowel-initial words does not appear until 13.5-16 month olds (Mattys & Juszcyk, 2001b). This huge discrepancy between infants' comprehension vocabulary and their segmentation performance has been noticed and various studies have investigated this "delay" to determine the cues that infant might utilize to segment vowel-initial words at an earlier age (Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005; Seidl & Johnson, 2008).

Brent and Siskind (2001) showed that only 9% of the utterances that infants are hearing consist of isolated words. Thus, to comprehend and learn new words infants first need to segment words from fluent speech. Segmenting words from fluent speech is more complicated than it sounds, mostly because words are not separated by silences in fluent speech. Unless a word is presented in isolation, the onset and/or the offset boundaries of the word are not clearly indicated. Given that word segmentation is difficult but important for language learners, not only to learn words, but also to acquire grammar (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006), infants' ability to do so has been investigated extensively for the past decade since the pioneering work by Jusczyk and Aslin (1995).

Numerous studies have looked at possible cues for word boundaries that both adults and infants might use to segment words. The substantial research on adults' spoken word recognition shows that adults use a variety of bottom-up cues, segmental as well as prosodic (e.g., Cutler, Mehler, Norris, & Segui, 1986; Mattys, White, & Melhorn, 2005; Salverda, Dahan, & McQueen,

2003), in addition to top-down cues such as known words (e.g., Norris. McQueen, & Cutler, 1995; Vroomen & de Gelder, 1995), to recognize words from fluent speech.

Word segmentation studies with infants have focused on the use of bottom-up cues – either segmental (e.g., transitional probabilities, Saffran, Aslin, & Newport, 1996; phonotactics, Mattys & Jusczyk, 2001b; phonological restrictions such as vowel harmony, Mintz & Walker, 2006; coarticulation, Johnson & Jusczyk, 2001; and allophonic variation, Jusczyk, Houston, & Newsome, 1999) or prosodic (e.g., stress, Jusczyk et al., 1999; and clause/phrase boundaries, Gout, Christophe, & Morgan, 2004) - and which cues are weighted more compared to the others when different cues collide (e.g., Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003).

Importantly, most of these studies have focused on infants' segmentation of consonant-initial words. There are a few studies in which segmentation of consonant-initial and vowel-initial words has been compared (Mattys & Jusczyk, 2001b; Nazzi et al., 2005), but their focus is more on explaining why infants show different developmental timelines, rather than on finding cues that might facilitate vowel-initial word segmentation. For example, Mattys and Jusczyk argue that vowel-initial words lack clear onsets unlike consonant-initial words, and this lack of perceptual cues might cause infants to favor consonant-initial words over vowel-initial words. As a consequence, infants younger than 16-month-olds are likely to misparse a sequence such as "cold ice" and listened longer to "dice" rather than "ice" (Mattys & Jusczyk, 2001b).

In the only study focusing on cues that facilitate the extraction of vowel-initial words (Seidl & Johnson, 2008), 11-month-olds were found to segment vowel-initial words under certain conditions. Specifically, given a salient utterance boundary cue, signaling either the onset or offset of a word, 11-month-olds were able to segment vowel-initial words. However, when

vowel-initial words were embedded in the middle of a sentence where there is no prosodic cue for word onset or offset, 11-month-olds failed to segment them.

Not only bottom-up cues, but also top-down cues, like the presence of known words, can facilitate infants' ability to segment words. Known words may cue either the onset or the offset of a novel word, which in turn delineates the boundary of the novel word, allowing its recognition. Bortfeld, Morgan, Golinkoff, and Rathbun (2005) illustrated that when presented after known content words (i.e., 'mommy', or the child's own name), infants can segment consonant-initial monosyllabic nouns at 6 months of age, which is earlier than previously suggested. English-learning infants have been shown to segment consonant-initial monosyllabic nouns only at 7.5 months of age (Jusczyk & Aslin, 1995). Thus, Bortfeld et al.'s study suggests that infants as young as 6-month-olds can use top-down information to segment novel words.

The natural question that follows is - what kinds of words can be categorized as "known words" for infants. A parallel literature suggests that not only content words, but also function words can be considered as "known words" for infants within the first year of life. Although function words lack obvious and concrete meanings, they occur frequently enough for infants to map the sounds and their phonetic forms, which is the first step in word learning. Studies measuring discrimination as well as segmentation have provided evidence for infants' knowledge of function words.

Cross-linguistically, phonological, distributional and acoustic cues, in languages as disparate as Mandarin Chinese, Turkish and English have been shown to support infants' ability to differentiate function words from content words (Shi, Morgan, & Allopenna, 1998; Shi, Werker, &Morgan, 1999). Consistent with this idea, the ability to distinguish function from content words seems to be independent of language experience. Specifically, newborns learning

either English or Chinese have been shown to distinguish English function words from content words (Shi et al., 1999). Further, various cross-linguistic studies have shown that infants can not only recognize function words from a [target function word + noun] phrase (7-9-month-olds for German-learning infants, Hohle & Weissenborn, 2003; and 6-8-month-olds for Canadian French-learning infants, Shi & Gauthier, 2005; Shi, Marquis, & Gauthier, 2006b), but also segment the following noun with the help of function words (8-month-old French-learning infants, Shi & Lepage, 2008; 8-13 month-old English learning infants, Shi, Cutler, Werker, & Cruickshank, 2006a).

Two studies provide preliminary evidence that infants may be able to use function words to segment or recognize the following words. Shi and colleagues (2006a) have demonstrated that English-learning 8-month-olds are able to use the frequently occurring determiner *the*, but not the less frequent determiner *her*, to segment pseudo nouns (*breek* or *tink*). Specifically, infants listened longer to a familiarized novel noun '*breek*' when familiarized with a high-frequency, real function word, plus novel noun combination, '*the breek*', and also the prosodically-matched, nonsense function word plus novel noun combination, '*kuh breek*'; however, they did not listen longer to a familiarized noun '*breek*' when familiarized with a less frequent, function word plus novel noun combination, '*her breek*'. This indicates that 8-month-olds are able to use frequently occurring function word *the* to segment the following words, although they don't have a detailed representation of it. By 11-months, infants were only successful when familiarized with '*the breek*' but not '*kuh breek*' indicating that they were not only able to use *the* in segmenting the following words, but also had a detailed representation of the function word *the*.

Shi and Lepage (2008) also show similar results with Canadian French-learning 8-month-olds. The infants were able to segment two novel nouns that were presented after the

frequent function word *des* (/de/, indefinite plural article), but not the nonsense function word *kes*. However, they failed to segment the novel nouns when they were presented after a less frequent function word *vos* (/vo/ 'your', plural form). Although infants learning English and Canadian French differ in the age at which they are sensitive to the phonetic detail in function words[1], both of these studies suggest that 8-month-old infants are familiar with high frequency function words, and are able to use these function words to segment the following nouns from two-syllable phrases. These studies, in line with Bortfeld et al.'s study (2005), indicate that infants as young as 8-months can use known function words, a top-down cue, to some extent to segment novel words that follow.

Shi et al.'s studies (2006a, 2008) as well as the Bortfeld et al.,'s study (2005) involve segmentation of monosyllabic consonant-initial words, using top-down cues (function words vs. known content words). However, these studies differ in task complexity. Bortfeld et al. expected infants to segment novel words from passages, whereas Shi et al. (2006a, 2008) required infants to segment novel words from [function word + novel word] phrases. Therefore, Shi et al.'s studies were less challenging for infants compared to that of Bortfeld et al.'s study. To compare the role of function words and other known content words in word segmentation tasks fairly, it is important to control for effects of task complexity.

Experiment 1 investigates whether infants can segment vowel-initial words when preceded by a familiar function word, e.g. '*the ice*'. This follows up on recent findings that infants use familiar words for segmentation (Bortfeld et al., 2005; Shi et al., 2006a, 2008), but applies it to vowel-initial words, a case that has proven challenging for infants in earlier studies (Mattys & Jusczyk, 2001b; Seidl & Johnson, 2008).

[1] French-learning 8-month-olds had a detailed representation of the frequently occurring function word *des*, whereas English-learning 8-month-olds did not have a detailed representation for the function word *the*.

2. Experiment 1

2.1 Methods

2.1.1 Participants

Sixteen full-term monolingual English-learning 8- (mean age = 238 days; range 226:254; 8 girls) and 16 11-month-olds (mean age = 343 days; range 326:346; 6 girls) participated in this experiment. According to parental report, none had a history of speech, language or hearing difficulties, nor did they have a cold or ear infection on the day of testing; and all were in good health and had at least 90% of their language input in English. Seven additional 8-month-olds and 9 additional 11-month-olds were tested but their data were discarded due to fussiness (n = 11), falling sleep (n = 1) or parental interference (n = 4).

2.1.2 Stimuli

The four VC words used in the current study were *ice*, *eff*, *oats* and *ash* (Mattys & Jusczyk, 2001b). Based on the lexical norms of the MacArthur-Bates Communicative Development Inventories (CDI; Fenson et al., 1994), 8- and 11-month-old English learning infants should treat these words as novel words. The words were recorded in four separate lists, with each list containing 15 repetitions of one of the four words. Also, two six-sentence passages containing the target words *ash* and *eff* were recorded. These passages were based on the passages used by Seidl and Johnson (2008). These six-sentence passages are listed in Appendix A. The position of the target words was always sentence–medial, following the function word *the*. As is typical, the function word *the* was produced phonetically as [ði] before the vowel-initial words (cf. Merriam-Webster's collegiate dictionary).

The stimuli were recorded by a 27-year-old female native English speaker from Tacoma, Washington. She was instructed to read the words and the passages in an animated voice as if talking to a pre-verbal infant. The stimuli were recorded in a soundproof booth using a Shure SM10A head-mounted microphone. All the stimuli were digitized at a sampling frequency of 22050Hz and 16-bit quantization. The average loudness level during playback was 73 dB. Acoustic measurements for the four lists of isolated words and for the two passages are reported in Table 1. All the acoustic analyses were done using Praat (Boersma & Weenink, 2010).

Table 1. Acoustic measurements for vowel-initial words

(standard deviations are shown in parentheses where appropriate)

Stimuli		Pitch (Hz)	Range of Pitch (Hz)	Length of Target Word (ms)	Sound file length (s)
Isolated words	Ash	278.9 (38.2)	219 ~ 355	889.1 (90.3)	22.97
	Eff	288.6 (41.8)	214 ~ 357	730.9 (137.2)	21.705
	Oats	294.1 (30.5)	248 ~ 338	884.7 (94.0)	22.268
	Ice	265.3 (36.4)	191 ~ 323	820.1 (60.5)	21.463
Passages	Ash	237.8 (44.2)	178 ~ 300	306.3 (45.8)	18.36
	Eff	262.8 (49.2)	196 ~ 313	214.8 (24.9)	17.94

2.1.3 Design

Infants were tested using the same paradigm as in Jusczyk et al., (1999), and Seidl and Johnson (2008). Testing was done in two phases. During the familiarization phase, the infants heard the passages containing the target words *ash* and *eff* till they accumulated 45 seconds of listening time to each passage. The trials continued to alternate until the criterion was met for both passages. During the test phase that followed, the infants were presented all four word lists consisting of two familiar (*ash* and *eff*) and two novel items (*ice* and *oats*). The four trials were

presented three times for a total of 12 test trials. The order of presentation of the word lists was randomized in each block. Listening time to familiar and novel test trials were averaged separately and compared statistically. To demonstrate segmentation, infants had to listen significantly longer to the familiar items compared to the novel ones.

2.1.4 Procedure

The Headturn Preference Procedure (HPP) was used to test infants. The infant sat on the caregiver's lap in the center of a three-sided booth. On each side panel, a red light was located at eye level. A green light was mounted on the center panel, also at eye level, and a movie-camera was mounted behind this panel, just above the green light. Each trial began when the green light on the center panel flashed. Once the infant oriented towards the center panel, one of the red lights on the side panels began to flash. When the infant turned her head towards that light, speech began to play. Stimulus presentation continued until the infant looked away from the flashing light for more than two consecutive seconds or at the end of the trial. The experimenter observed the infant through a monitor connected to the camera facing the infant and recorded infant looking time. Both the caregiver and the experimenter wore noise cancelling headphones that delivered masking music to prevent influencing the infants' behavior.

2.2 Results

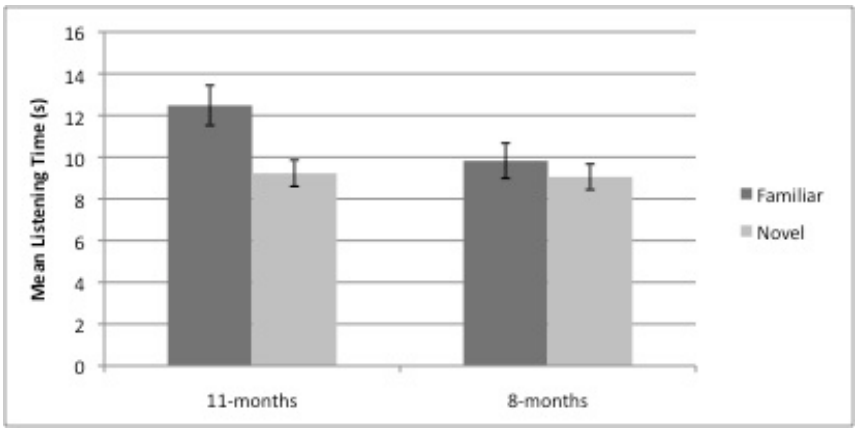
Average listening times to the familiar and novel items in the two age groups are presented in Figure 1. A two-way mixed ANOVA with listening time as the dependent variable, and age (8 month-olds vs. 11 month-olds) as a between-subjects variable, and trial-type (familiar vs. novel) as a within-subjects variable was carried out. The main effect of trial-type was

significant ($F(1,15) = 12.550$, $p = 0.001$). The main effect of age was not significant ($F(1,15) = 2.293$, $p = .140$). There was a significant interaction between age and trial-type ($F(1,15) = 4.775$, $p = .037$) so post-hoc comparisons were performed to confirm that infants in each age group succeeded in the segmentation task.

Out of the 16 8-month-olds tested, 9 listened longer to the familiar words compared to the novel words. The average listening times to the familiar words was 9.82 s ($SD = 3.3$) and 9.05 s ($SD = 2.4$) for the novel words. Although this difference was in the right direction, a paired sample t-test revealed that it was not significant [$t(15) = 1.143$, $p = .134$; $d = 0.262$]. Thus, 8-month-olds were not able to use function words to segment vowel-initial words embedded in the middle of carrier sentences. The small effect size ($d = 0.262$) suggests that simply testing more 8-month-olds is unlikely to result in a significant effect.

In contrast, out of the 16 11-month-olds tested, 14 listed longer to the familiar words compared to the novel words. The average listening times were 12.48 s ($SD = 3.83$) for the familiar words and 9.23 s ($SD = 2.5$) for the novel words. A paired sample t-test revealed that this difference was significant [$t(15) = 4.204$, $p < .001$; $d = 1.004$]. This result clearly indicates that 11-month-olds learning English are able to use function words to segment vowel-initial words embedded in the middle of carrier sentences.

Figure 1. Average listening time (+/- *SE*) to familiar and novel words



2.3 Discussion

Contrary to the results from Seidl and Johnson (2008)'s study, in Experiment 1 we have shown that 11-month-olds successfully segment vowel-initial words when they appear in the middle of sentences. The only difference between the two studies is the use of the function word *the* before the sentence-medial target words. This indicates that the known function word *the* facilitates 11-month-old infants' vowel-initial word segmentation.

Unlike the 11-month-olds, the 8-month-olds were not able to use the function word *the* to segment a vowel-initial word placed sentence-medially. This finding contrasts with that of Shi et al. (2006a), who found that 8-month-olds could segment consonant-initial words after the function word [ðə] or a prosodically-matched foil [kə]. There are several possible explanations, not mutually exclusive, which may account for this disparity. First, it is possible that 8-month-olds failed in this experiment but not in Shi et al.'s study because the task here was harder. It may be harder for infants to segment vowel-initial words, as has been argued previously. Or infants might find it harder to segment words embedded in the middle of sentences, rather than from short phrases like '*the breek*'.

The second possibility is more intriguing. Recall that in the study by Shi et al., (2006a), 8-month-olds were able to segment consonant-initial words when the words were presented either after the function word *the* [ðə], or its prosodically-matched counterpart *kuh* [kə]. Both of these forms have phonological and acoustic characteristics of function words: they have the reduced schwa [ə]. Due to its phonological and acoustic similarity to [ðə], 8-month-olds might treat *kuh* as a function word as well and use it to segment words. However, it is possible that the 8-month-olds were not able to recognize [ði] as an allomorph of [ðə], because it has a full vowel [i] and as such did not treat it as a frequent function word. Future research is needed to test this hypothesis.

Experiments 2 and 3 were designed to eliminate two alternative explanations that might account for these results. Experiment 2 was designed to rule out the hypothesis that 11-month-olds were succeeding at segmenting vowel-initial words in Experiment 1 by exploiting the phonotactic knowledge that two consecutive vowels do not appear within words in English (vowel hiatus). That is, Experiment 2 aimed to show it was the occurrence of *the* specifically, rather than the occurrence of a V#V sequence, that enabled 11-month-olds to succeed in Experiment 1.

Research shows that infants as young as 9-month-olds are not only sensitive to native language phonotactics (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994) but also able to use phonotactics to segment words (Mattys & Jusczyk, 2001b; Mattys, Jusczyk, Luce, & Morgan, 1999). Thus, it is possible that 11-month-olds in Experiment 1 succeeded due to their phonotactic knowledge about vowel hiatus. Given that 8-month-olds were unable to segment in Experiment 1, there is no evidence that they can exploit such phonotactic regularities.

Experiment 3 was designed to rule out the possibility that 11-month-olds were using allophonic variation in the experimental stimuli, a glottal stop (or a glottalized vowel) rather than the familiar function word *the* per se, in segmenting vowel-initial words. In American English, a vowel is frequently glottalized (Pierrehumbert, 1995; Dilley, Shattuck-Hufnagel, & Ostendorf, 1996) or a glottal stop is inserted (Dilley et al., 1996; Umeda, 1978) at the onset of vowel-initial words, especially when these words appear in sentence-initial position. Thus, glottalized and non-glottalized instances occur as allophones of the same vowels.

Previous research indicates that infants as young as 9-month-olds can use allophonic cues to segment words. Jusczyk, Hohne, and Bauman (1999) have shown that although 9-month-olds require both allophonic and distributional cues to segment bisyllabic words from fluent speech, by 10.5 months, infants are able to rely solely on allophonic cues. Experiment 3 was conducted to determine whether infants were relying on allophonic cues to segment vowel-initial words in Experiment 1. Again, given that 8-month-olds were unable to segment in Experiment 2, there is no evidence that they can exploit such allophonic variation.

3. Experiment 2

In Experiment 1, infants were presented the function word *the* followed by vowel-initial target words. In Experiment 2, instead of presenting infants [the + vowel-initial word] frame, [CV + vowel-initial word] frames, where the CV was a content word, were presented to 11-month-olds. If infants in Experiment 1 were using their knowledge of phonotactic regularities in segmenting vowel-initial words, then 11-month-olds should successfully segment sentence-medial, vowel-initial words in Experiment 2 as well. However, if infants in Experiment 1 were

using the function word *the* in the segmentation task, then 11-month-olds should fail to segment the sentence-medial, vowel-initial words in Experiment 2.

3.1 Methods

3.1.1 Participants

Participants were sixteen full term monolingual, English-learning 11-month-olds. Selection criteria were identical to that in Experiment 1. 6 additional infants were tested, but their data were discarded due to fussiness (n = 5) and falling sleep (n = 1).

3.1.2 Stimuli

The target words were identical to that used in Experiment 1 (*ash*, *eff*, *ice*, and *oats*). The difference between the two experiments was that in Experiment 2, instead of the function word *the*, several different words that ended in a vowel (such as *saw*, *pray*, *two, etc.*) preceded the vowel-initial target words (Appendix C). The speaker, instructions, and recording set-up were identical to that in Experiment 1. Acoustic measurements for the four passages are reported in Table 2.

Table 2. Acoustic measurements for vowel-initial words

(standard deviations are shown in parentheses where appropriate)

Stimuli		Pitch (Hz)	Range of Pitch (Hz)	Length of Target Word (ms)	Sound file length (s)
Isolated words	Ash	278.9 (38.2)	219 ~ 355	889.1 (90.3)	22.97
	Eff	288.6 (41.8)	214 ~ 357	730.9 (137.2)	21.705
	Oats	294.1 (30.5)	248 ~ 338	884.7 (94.0)	22.268
	Ice	265.3 (36.4)	191 ~ 323	820.1 (60.5)	21.463
Passages	Ash	285.3 (82.2)	191 ~ 399	328.8 (63.5)	18.36
	Eff	290.1 (72.7)	191 ~ 356	269.6 (63.8)	18.56
	Oats	287.3 (77.7)	219 ~ 430	334.5 (75.2)	17.67
	Ice	278.3 (104.9)	177 ~ 422	315.8 (59.5)	19.86

3.1.3 Design

The design was identical to that used in Experiment 1, with one modification. Half of the infants heard the target sentences with *eff* and *ash* in the familiarization phase whereas the other half heard oats and ice in the familiarization phase.

3.1.4 Procedure

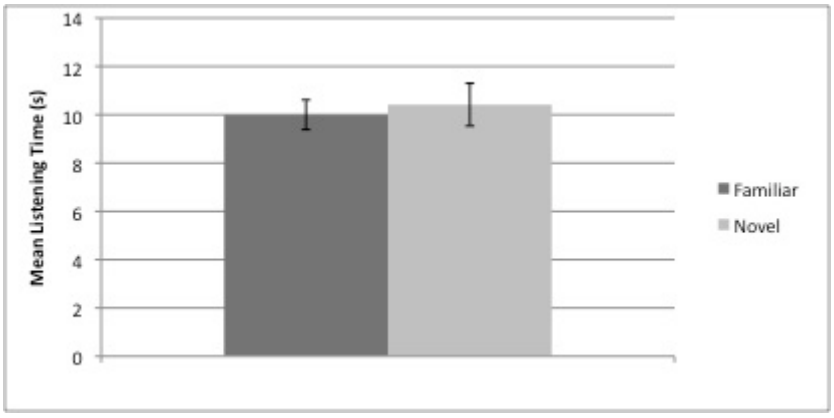
The procedure was identical to that of Experiment 1.

3.2 Results

Average listening times to the familiar and novel items were measured for each infant. Out of 16 infants, 6 listened longer to the familiar words compared to the novel words. Across all participants, the average listening times were 9.99s (*SD* = 2.38) for the familiar words and 10.41

s (*SD* = 3.32) for the novel words. A paired sample t-test revealed that this difference was not significant [$t(15) = -.608$, $p = .552$, $d = -.557$]. Figure 2 illustrates this result.

Figure 2. Average listening time (+/- *SE*) to familiar and novel words



A two-way mixed ANOVA with listening time as the dependent variable, trial-type (familiar vs. novel) as the within-subjects variable, and experiment (1 vs. 2) as the between-subjects variable was done to compare the performance of 11-month-olds' on Experiments 1 and 2. The main effect of trial-type (familiar vs. novel) was significant ($F(1,15) = 6.805$, $p = .014$). There was no significant main effect of experiment ($F(1,15) = .639$, $p = .430$). Most importantly, there was a significant interaction between trial-type and experiment, ($F(1,15) = 12.125$, $p = .002$). Thus, 11-month-olds behaved differently in the two experiments, they were successful at segmenting when given the frequent function word *the* in Experiment 1, but not when given phonotactic cues, specifically, vowel hiatus, in Experiment 2.

3.3 Discussion

Experiment 2 shows that 11-month-olds failed to segment vowel-initial words when they were preceded by monosyllabic words ending in vowels. This indicates that the 11-month-olds

cannot simply use phonotactic regularities to detect vowel-initial words that are embedded sentence-medially. This result supports previous studies on vowel-initial segmentation in showing that vowel-initial words are difficult to segment.

Results from this experiment also suggest that phonotactics regularities involving vowels are learned later in development than other types of phonotactic regularities involving consonants. For instance, previous studies have shown that 8.5-month-olds can use the allophonic variations of [d] to segment dice from "roll dice", but not "cold ice" (Mattys & Jusczyk, 2001a & b).

4. Experiment 3

Previous studies on segmentation of vowel-initial words did not systematically control for allophonic variations. Thus, infants heard no or very few glottal stops or glottalized vowels in familiarization passages yet almost always heard glottalized allophones in test items (Seidl & Johnson, 2008). In explaining the delay in vowel-initial word segmentation, Seidl and Johnson (2008) have suggested that infants might treat glottal stops as phonemes in English, and consequently fail to match vowel-initial words in familiarization passages and testing items. If indeed infants treat glottal stops as phonemes, as Seidl and Johnson suggest, then what infants are dealing with are not vowel-initial words, but consonant-initial words. Thus, 11-month-olds should be able to segment vowel-initial words if a glottal stop precedes it.

In Experiment 3, 11-month-olds were presented with [CV + glottal stop [ʔ] + vowel-initial word] frame. If infants in Experiment 1 were using the glottal stop as the onset of the vowel-initial words, which can cue the onset of vowel-initial words, then 11-month-olds should be able to segment sentence-medial vowel-initial words in Experiment 3 as well. However, if

infants in Experiment 1 were using the function word *the* in the segmentation task, then the 11-month-old should again fail in Experiment 3.

4.1 Methods

4.1.1 Participants

Participants were sixteen full term monolingual, English-learning 11-month-olds. Selection criteria were identical to that in Experiments 1 and 2. 8 additional infants were tested, but their data were discarded due to fussiness (n = 5), parental interference (n = 1), technical issues (n = 1) and falling sleep (n = 1).

4.1.2 Stimuli

The target words were identical to that used in Experiments 1 and 2 (*ash*, *eff*, *ice*, and *oats*). The familiarization passages were the same as Experiment 2, several different words that end with a vowel (such as *saw, pray, two*, etc) preceded the vowel-initial target words (Appendix C). Additionally, the speaker, who was a trained phonetician, was instructed to produce the target words with a glottal onset. The rest of the instructions and recording set-up were identical to that in Experiments 1 and 2. Acoustic measurements for the four passages are reported in Table 3.

Table 3. Acoustic measurements for vowel-initial words

(standard deviations are shown in parentheses where appropriate)

Stimuli		Pitch (Hz)	Range of Pitch (Hz)	Length of Target Word (ms)	Sound file length (s)
Isolated words	Ash	278.9 (38.2)	219 ~ 355	889.1 (90.3)	22.97
	Eff	288.6 (41.8)	214 ~ 357	730.9 (137.2)	21.705
	Oats	294.1 (30.5)	248 ~ 338	884.7 (94.0)	22.268
	Ice	265.3 (36.4)	191 ~ 323	820.1 (60.5)	21.463
Passages	Ash	250.66 (49.2)	183 ~ 297	393.7 (68.5)	18.9
	Eff	253.09 (56.41)	186 ~ 323	279.3 (34.5)	18.92
	Oats	249.75 (49.42)	187 ~ 308	382.3 (76.7)	19.83
	Ice	252.8 (69.8)	177 ~ 382	396.2 (49.1)	19.37

Glottalization is known to be extremely variable even within-speakers (Dilley et al., 1996) and can be characterized using several different acoustic measures (Redi & Shattuck-Hufnagel, 2001). Following Redi and Shattuck-Hufnagel (2001), we report the following four measures to index glottalization in our stimuli: duration of full glottal stop, and extent of aperiodicity / creak / period-doubling. Aperiodicity, creak and period-doubling can occur either before or during vowel-initial words. Therefore, we report its extent during the target word as well as in the duration preceding the target vowel. We report glottalization indices for the stimuli used in Experiment 3 as well as Experiment 1 for comparison. This is shown in Table 4.

As expected, in the stimuli for Experiment 3, all target words were produced with a glottal stop. Further, most target words were also accompanied by glottalization, either during the target word or before it. In contrast, in the stimuli for Experiment 1, only 2 out of 12 target words were produced with a glottal stop. Even when present, the glottal stop cue was very short and variable in duration.

Table 4. Glottalization indices for stimuli used in Experiment 3s and 1

(standard deviations shown in parentheses)

Word or passages		Full glottal stop (duration in ms)	Before the target word (duration in ms)	During the target word (duration in ms)
Passages in Experiment 3	Ash	99.33 (30.25)	20.08 (8.52)	8.83 (13.86)
	Eff	101.16 (36.68)	17 (9.16)	27.23 (10.71)
	Oats	96.23 (32.61)	22.53 (8.6)	-
	Ice	85.33 (19.03)	39.33 (29.13)	18.16 (22.33)
Passages in Experiment 1	Ash	13(31.84)	29.83 (34.59)	37.83 (43.92)
	Eff	10.66 (26.12)	-	26 (32.29)

4.1.3 Design

The design was identical to that of Experiment 2.

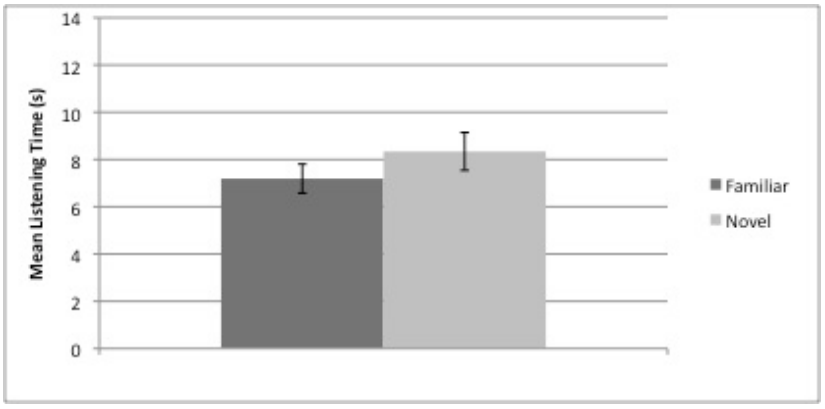
4.1.4 Procedure

The procedure was identical to that of Experiments 1 and 2.

4.2 Results

Average listening times to the familiar and novel items were measured for each infant. Out of 16 infants, 6 listened longer to the familiar words compared to the novel words. Across all participants, the average listening times were 7.19s (*SD* = 2.44) for the familiar words and 8.33 s (*SD* = 3.2) for the novel words. A paired sample t-test revealed that this difference was not significant [$t(15) = -1.299$, $p = .213$, $d = -.400$]. Figure 3 demonstrates this result.

Figure 3. Average listening time (+/- *SE*) to familiar and novel words



Again, a two-way mixed ANOVA with listening time as the dependent variable, trial-type (familiar vs. novel) as the within-subjects variable, and experiment (1 vs. 3) as the between-subjects variable was done to compare the performance of 11-month-olds' on Experiments 1 and 3. The main effect of trial-type (familiar vs. novel) was not significant ($F(1,15) = 3.202$, $p = .084$); overall, 11-month-olds had longer listening times in Experiment 1 compared to Experiment 3. There was a significant main effect of experiment ($F(1,15) = 11.690$, $p = .002$). Crucially, there was a significant interaction between trial-type and experiment ($F(1,15) = 14.028$, $p = .001$). This suggests that the 11-month-olds behaved differently in Experiments 1 and 3.

4.3 Discussion

Experiment 3 demonstrates that 11-month-olds failed to segment vowel-initial words even when a glottal stop [ʔ] was present both in the familiarization passages and test items. This result shows that it is not the phonetic mismatch between the target words in the passages and the list that contributes to infants' failure in previous research on vowel-initial word segmentation. These results also show that the presence of a glottal stop signaling the onset of a vowel-initial

word embedded sentence-medially does not help 11-month-olds segment them. In summary, the 11-month-olds' success in Experiment 1 and their failure to do so in Experiments 2 and 3 illustrates that it is the function word *the* that facilitates 11-month-olds' segmentation of sentence-medial vowel-initial words.

5. General discussion

The current study was designed to find cues that 8 and 11-month-old infants might use in segmenting vowel-initial words. In Experiment 1 we showed that 11-, but not 8-month-olds, were able to use a top-down cue, the frequently occurring function word *the*, to segment vowel-initial words in a very challenging environment where vowel-initial words appear in the middle of carrier sentences. In contrast, when the target words were preceded by a monosyllabic word ending in a vowel, 11-month-olds failed to segment vowel-initial words. Neither the phonotactic cues (Experiment 2) nor the presence of a glottal stop at the beginning of the vowel initial words (Experiment 3) supported 11-month-olds' segmentation of vowel-initial words embedded sentence-medially.

The stimuli in Experiments 2 and 3 differed from that in Experiment 1 in one other way that might explain infants' success in the latter but not former two experiments. In Experiment 1, target words were always presented in a fixed frame [the + vowel-initial word], whereas in Experiments 2 and 3 variable frames [CV + vowel-initial word] were used. It is possible that this made the word segmentation process more challenging in Experiments 2 and 3.

Existing research on the role of variability in the input actually suggests that variable frames may in fact help the language acquisition process. The benefit of variability in phonological processing has been well documented (McMurray & Aslin, 2005; Rost &

McMurray, 2009). These studies have shown that infants are sensitive to within category variation and profit from variable structures in detecting words. Further, variable frames provide transitional probability cues to signal words onsets and offsets (Gomez, 2002; Saffran, et al., 1996). Thus, although our 11-month-olds did not get any benefit from variability, we do not believe that the presence of variable frames in itself made word segmentation more challenging in Experiments 2 and 3.

The results from this study have four implications. First, 11-month-olds can not only segment vowel-initial words in sentence-initial or -final position, as has been shown previously (Seidl & Johnson, 2008), they also succeed when these words are placed sentence-medially. These results are in contrast with early studies, where only 13-16.5-month-olds successfully segment vowel-initial words (Mattys & Jusczyk, 2001b).

Second, the current study shows one way in which function elements are likely to facilitate children's language development. Just like frequently occurring content words, such as "mommy" or a baby's name (Bortfeld et al., 2005), highly frequent function words also bootstrap pre-linguistic infants' segmentation of new word forms. Previous studies on function word acquisition have shown a facilitative effect of frequent function words in segmenting consonant-initial words from two-word phrases (Shi et al., 2006a & b; 2008). Our results show that this facilitative effect can scale up to the challenge of connected speech, i.e., full sentences and paragraphs, where the target word is a vowel-initial word embedded sentence-medially.

Third, the results suggest that phonotactic regularity involving vowels might be learned later than ones involving consonants. Previous studies on the role of phonotactics in word segmentation have shown that 8.5-month-olds are able to use phonotactic cues involving

consonants to segment the following words. In contrast, 11-month-olds tested in Experiment 2 failed to use phonotactic cues about vowel hiatus to segment vowel-initial words.

The results from Experiment 2 are consistent with a body of research showing that adults as well as infants treat consonants and vowels differently in speech processing. Based on language samples from brain-damaged patients, researchers have argued that consonants and vowels are represented as two distinct categories in the brain (Caramazza, Chialant, Capasso, & Miceli, 2000). Functionally, consonants have been proposed to be more important in lexical processing and acquisition, whereas vowels have been thought to be essential in prosodic and syntactic processing/acquisition (Nespor, Peña, & Mehler, 2003). More specific to acquisition, both French- and English-learning 30-month-olds have been shown to neglect a vocalic rather than a consonantal change in a word learning task, if they are presented with a choice between the two (Nazzi, 2005; Nazzi et al., 2005; but see Mani & Plunkett 2007, 2008; Mani, Coleman, & Plunkett, 2008 for different results). In sum, there are good reasons to believe that infants treat consonants and vowels differently, and that this behavior might extend to the learning of phonotactic regularities involving consonants versus vowels.

Finally, these results add to our understanding of the role of allophonic variations in word segmentation. Previous studies have demonstrated that infants as young as 9-months are able to segment words using allophonic cues (Jusczyk et al., 1999; Mattys & Jusczyk, 2001b; Mattys et al., 1999). However, even 11-month-olds tested in Experiment 3 failed to segment vowel-initial words using the glottal stop/glottalized vowel allophone. These discrepant results can be explained in several ways. First, in previous studies the target words usually appeared twice at the initial position, twice sentence-medially and twice at the end of the sentence. In contrast, in our study, target words were only presented sentence-medially. Given evidence that sentence-

medial words are harder to segment than target words embedded at the ends of utterances (Seidl & Johnson, 2006, 2008), it is possible that infants can use allophonic cues in segmenting words only when the words appear at utterance boundaries. Second, unlike other allophones in English, both degree and rate of glottalization vary a lot, within as well as across individuals (Redi & Shattuck-Hufnagel, 2001). Besides signaling allophonic differences, glottalization in English also varies with register and speech rate and most prominently with the presence of prosodic boundaries (Eddington & Channer, 2010). All the above reasons are likely to make glottalization (including the presence of a glottal stop) a poor cue for word segmentation resulting in 11-month-olds lack of sensitivity to it. Third, previous studies used allophonic cues to indicate word offset boundaries, whereas glottaliztion is a cue that signals word onset. It is possible that this difference in position within a syllable might have played a crucial role in explaining 11-month-olds' failure to use glottalization as a cue to word segmentation.

In conclusion, parental reports as well as the results from Seidl and Johnson (2008) demonstrate that infants younger than the previous studies have suggested (13-16.5 months of age) can segment vowel-initial words in certain contexts. The current paper demonstrates one context, which infants might utilize in learning vowel-initial words.

Appendix A Passages Used in Experiment 1

Eff	Ash
I like how the eff runs the circus.	It seems like the ash is very creative.
I wonder if the eff wants to juggle too.	I see the ash can stand on his head.
We know the eff has a great time.	I see that the ash named this dish.
We're sure the eff would love to learn.	Somehow the ash makes us laugh.
I think the eff could do a great job.	We suspect the ash loves to cook.
They say the eff hires clowns all year.	I'm sure the ash learned to do flip.

Appendix B Passages Used in Experiments 2 & 3

Ice	Oats
He wants to be ice when he grows up.	I saw oats standing on his head.
We have seen raw ice for months.	My sister and I pray oats gets better.
They knew ice hires clowns all year.	There are three oats lying on the grass.
They are giving out free ice today.	There is a picture of gray oats in my room.
I grow ice in my back yard.	I wonder if new oats wants to learn.
They say true ice is rarely found these days.	I see two oats jumping around.

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