The Role of Segmentation in Lexical Acquisition in Children

Rôle de la Segmentation Dans l'Acquisition du Lexique chez les Enfants

Sarah Smits-Bandstra

Abstract

This position paper proposes that the development of a sophisticated segmentation system is one factor that may play an important role in the vocabulary spurt in children. Segmentation is the ability of a listener to pick out words from the acoustically continuous steam of speech. The argument is put forth that initially children segment words using prelexical strategies alone and are able to do this based on their early sensitivities and the rich acoustical signals in the speech input they receive. Further evidence demonstrates that adults use a sophisticated segmentation system that efficiently incorporates both prelexical and lexical cues from the speech input. Finally, the results of several important segmentation studies are presented to support the main hypothesis of the paper, that the development of an integrated segmentation system relying on both prelexical (bottom-up) and lexical (top-down) segmentation cues by children coincides with and may possibly be an important determinant of the timing of the vocabulary spurt.

Abrégé

Le présent énoncé de position avance que le développement d'un système complexe de segmentation serait l'un des facteurs jouant un rôle important dans l'accélération de l'acquisition du vocabulaire chez les enfants. La segmentation est la capacité de l'auditeur à repérer les mots dans le flot acoustique continu de la parole. L'argument développé propose qu'au départ les enfants segmentent les mots à partir de stratégies pré-lexicales seulement et y arrivent grâce à leur sensibilité précoce et à la richesse des signaux acoustiques des messages verbaux qu'ils entendent. D'autres éléments montrent que les adultes ont recours à un système complexe de segmentation qui intègre à la fois des indices pré-lexicaux et post-lexicaux dans la parole. Enfin, les résultats de plusieurs études importantes sur la segmentation sont cités pour corroborer la principale hypothèse de l'article, c'est-à-dire que l'acquisition chez les enfants d'un système de segmentation intégré reposant sur des indices pré-lexicaux (ascendant) et lexicaux (descendant) correspond à une accélération de l'acquisition du vocabulaire et pourrait en être un déterminant important.

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Introduction

Parents and speech-language pathologists alike can testify to the painfully slow rate at which the first 10 to 50 words are acquired in typically developing children. Research has demonstrated that vocabulary acquisition is gradual for several months after the first word (Plunkett, 1993). As many as 4 or more months may elapse as the typically developing child progresses from a vocabulary size of 1 to a vocabulary size of 10 words (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987).

If one considers the difficulty an infant faces in trying to pick single words out of a perceptually continuous stream of speech, this rate of lexical acquisition is not surprising. Before being able to learn any new words, the new language learner must first be able to determine where one word stops and another word begins in the sentences they hear. The ability of a listener to divide up the speech stream into linguistically and psychologically meaningful units is called segmentation (Cairns, Shillcock, Chater, & Levy, 1997).

Research studies have shown that children at this early, slow stage in vocabulary development depend on prelexical acoustic cues (e.g., stress, pausing, pitch, intonation, clause breaks) to understand the speech they hear (Christiansen & Chater, 2001). These children also demonstrate slightly more advanced language skills when exposed to simplified language input, *motherese* (Messer, 1981; Peters, 1985), and repetition (Woodward, Markman, & Fitzsimmons, 1994). These types of language manipulations make the most of prelexical acoustic cues such as stress, intonation and pause to help a child segment the speech stream.

After a child has acquired a lexicon of approximately 50-100 words, the rate at which he or she acquires new vocabulary words increases at a phenomenal rate. This increase in vocabulary is referred to as the vocabulary spurt. It should be noted that some children exhibit more obvious spurts than others and at different ages or vocabulary sizes (Bates, Marchman, Thal, Fenson, Dale, Reznick et al., 1994). There appears to be a qualitative change in the way children process language that precipitates this quantitative change in vocabulary size (Golinkoff et al., 1987; Plunkett, 1993; Woodward et al., 1994). To the clinician's eye, children just suddenly seem to "get the knack of" learning new words.

Many children transitioning into the vocabulary spurt use a strategy called *fast mapping,* wherein they can pick out and learn new vocabulary words from the surrounding sentence after only minimal exposure to it. They may need to hear the new word only one time in order to establish a link between the word and its referent (Mervis & Bertrand, 1995). The emergence of fast mapping indicates that children are no longer dependent on prelexical cues alone to pick words out of the speech stream, because they no longer need to rely so heavily on prelexical cues such as repetition and intonation to segment and learn new words. Rather, children at this stage already have a vocabulary size of 50 words or more and are able to use lexical strategies (knowledge about words) in addition to prelexical strategies to segment utterances directed to them.

This paper proposes that the development of a mature, speech segmentation system (one that integrates both prelexical and lexical segmentation) is associated in time with the onset of the vocabulary spurt of children. It is important to establish those factors that potentially play a role in the onset of the vocabulary spurt for clinical reasons. If it is empirically shown that segmentation strategies play a part in rapid word learning, then these segmentation skills can be targeted in therapy for children with delayed vocabulary skills.

This paper puts forward several arguments. First, infant-directed speech is rich with acoustic cues that can be used for prelexical segmentation. Second, from an early age the infant appears to have an inherent sensitivity to these acoustic cues. Third, after a certain number of vocabulary words are learned, children demonstrate the ability to use a mature, adult-like segmentation system that integrates both prelexical and lexical segmentation cues. Finally, results of several studies suggest that the development of an integrated segmentation system is associated with, and may be an important determinant of, the onset of the vocabulary spurt.

Lexical Acquisition through Segmentation

To begin to understand and use language a child must segment continuous speech input into units corresponding to words and word boundaries. Words in continuous speech are usually woven together through co-articulation to form a seamless stream of acoustic and phonetic information without intervening silence (Gow & Gordon, 1995). A child must be able to segment speech despite the acoustic variability of words, contexts, talkers, and slips of the tongue (Mattys & Jusczyk, 2001). To learn new vocabulary words, a child must first be able to segment words from the speech stream. Theories of word segmentation distinguish between processes that operate based on a prelexical or a lexical representation of continuous speech (Davis, Marslen-Wilson, & Gaskell, 2002).

Prelexical Segmentation

The Prelexical perspective is often referred to as a bottom-up account because it emphasizes the importance of the identification of acoustic cues that mark word boundaries in running speech (Christiansen & Chater, 2001). According to Prelexicalists, the preverbal infant is initially constrained to segment speech input using some method that does not require word recognition (Christiansen & Chater, 2002). The young infant neither has nor requires any top-down processing about the lexical items; rather lexical access is initiated after word onsets have been identified by their perceptual features. In other words, children are able to segment and learn new words using acoustic cues in the speech directed to them. In support of this perspective there is some evidence to suggest that learning new words is more successful when adults emphasize acoustic segmentation cues such as intonation, pause and repetition (Murray, Johnson, & Peters, 1990; Peters, 1985).

Researchers who support the Prelexical perspective typically fall along a continuum from Nativism (infants have an innate ability to segment and learn new words) to Emergentism (infants' segmentation skills are developed from exposure to a rich linguistic environment). The following section will present research from both perspectives. These two perspectives are presented as a continuum and not a dichotomy in this paper because (a) findings from many of the language studies conducted with infants can be used to support both perspectives to varying degrees, and (b) both of these theoretical views support the notion that preverbal children tend to use bottom-up, acoustic information rather than lexically-based strategies early on in word learning. This paper goes one step further to argue that children make an important transition toward integrating both prelexical and lexical segmentation

strategies during development, and that this integration is associated with the onset of the vocabulary spurt.

Prelexical Nativism

Researchers on the Nativist end of the Prelexical continuum propose that infants possess sensitivities to acoustical stimuli that can be used to segment the speech they hear. The sensitivities they demonstrate are at least partially automatic and are triggered by the nature of acoustical input received from the environment (Meltzoff, 1999). Furthermore, children are sensitive from the beginning to the information value of cues in their native language, and this sensitivity seems to be an important factor accounting for segmentation and comprehension (Baldwin & Markman, 1989). Studies falling at the Nativist end of the continuum demonstrate that (a) various prelexical segmental cues are present in the speech directed to infants, and (b) infants show early listening preferences to these cues.

Messer (1981) hypothesized that the pre-verbal child must be able to locate the referential word in the speech stream using nonverbal information in order to identify the object to which the reference is made. He further proposed that prelexical cues must be available for the child to isolate the referential word contained within multiword utterances. He sampled the acoustic amplitude of the speech that mothers directed to their 14-month-olds during free play. Fifteen mother-infant pairs (8 female and 7 male children) were included in the study. Messer found that object names were frequently the loudest words of an utterance and were also likely to be positioned at the end of utterances. He proposed that louder or stressed words may be articulated more clearly than other words, facilitating their segmentation using the suprasegmental features of speech (Messer, 1981). Messer's study did not speak directly to the early listening preferences of the infant; rather the results of this study indicated only that prelexical cues were present in caregivers' speech and were available for the infant to use for segmentation. Further research in this area, presented below, presents evidence that spoken language stimulates an infant's natural listening preferences and may assist segmentation of object names from the speech stream (Baldwin & Markman, 1989; Hirsh-Pasek et al., 1987; Polka & Werker, 1994).

Baldwin and Markman (1989) proposed that infants have a predisposition to attend preferentially to objects in the presence of language. They designed a study to investigate if infants' attention to new objects was enhanced when a label in a naturalistic motherese frame was provided (e.g., "It's a pyramid"). They compared how long eighteen 10- to 14-month-olds looked at unfamiliar toys when they were presented with or without a labeling phrase. The authors found a tendency for language to sustain infants' attention to objects over and above a labeling gesture (e.g., pointing) in children as young as 10 months. This study was limited however, in its ability to differentiate specific aspects of spoken language that served to capture the attention of infants.

Further investigation has pinpointed the exaggerated prosodic features of infant-directed speech as stimulating the early listening preferences of infants. Cooper and Aslin (1990) examined whether twelve 1-month-olds and sixteen 2-day-olds looked longer at a visual stimulus when looking was paired with motherese or with adult-directed speech. The authors found that, from birth, infants demonstrate preference for the exaggerated prosodic features of motherese.

Studies have also been conducted to assess which features of an utterance were most salient to the early listening preferences of infants (Hirsh-Pasek et al., 1987; Polka & Werker, 1994). Hirsh-Pasek et al. employed a preferential-looking procedure (see Spelke, 1979) to examine the sensitivity of 7- to 10-month-old infants to clausal pauses. They found that infants preferred to hear native speech with appropriate clause breaks as opposed to inappropriate clause breaks suggesting they were able to detect units such as clauses. These researchers reported that clause boundaries were often marked by changes in prosody to which the infant may have been sensitive including pauses, segmental lengthening of the syllable preceding the clause, a rise or fall in pitch before the clause, and stress marking to indicate clause boundaries (Hirsh-Pasek et al., 1987).

As mentioned in the introduction to the section *Prelexical Segmentation,* this study can be seen to support both Nativist and Emergentist perspectives. Although the listening preference was detected early in development, it cannot be ruled out that it developed as a result of exposure to speech input. The Nativist leanings of the authors were evident from their focus on the sensitivities inherent to the infant. Regardless, the study demonstrated that prelexical segmentation cues were present in infant-directed speech and infants were sensitive to them.

Other acoustic features revealed as useful in word-boundary marking were glottal stops, word-segment durations, and increased aspiration on voiceless stops (Davis et al., 2002; Gow & Gordon, 1995). Studies have shown that the newborn's perceptual system has early sensitivities/preferences that facilitate the recognition and processing of these perceptual features (Polka & Werker, 1994).

The evidence presented so far indicates that the infant is in possession of sensitivities important for segmentation and language acquisition (Hirsch-Pasek et al., 1987; Messer, 1981; Polka & Werker, 1994). The results of these studies can also be interpreted to suggest that, theoretically, infants are capable of using the available cues to segment speech. However, one must look to the Emergentism end of the continuum to find studies demonstrating *how* infants might learn to segment the speech stream.

Prelexical Emergentism

Plunkett (1998) reported that computer-model research provides evidence that the input children receive is rich in acoustic cues that help the infant learn to segment speech. Both Nativists and Emergentists agree that the newborn mind comes equipped with a sophisticated set of constraints for processing the linguistic environment; however, Emergentists specify with computer modeling how the newborn mind could capitalize on these sensitivities and learn segmentation from the prelexical patterns implicit in the speech input (Plunkett, 1998). In other words, the focus of Emergentism is on the rich informative nature of the input for segmentation rather than the rich processing abilities of the infant.

According to MacWhinney (1998), Emergentism posits that prelexical segmentation can be achieved from patterns implicit in the input and interactions with the biology of the cognitive system. He proposed that neural network models like Emergentism are capable of accounting, in part, for the early stages of language development. Researchers from the Emergentist end of the continuum suggest that segmental strategy adoption and rule-like behavior may be possible with fewer assumptions about innate knowledge (Cicchetti, 1993; MacWhinney, Leibach, Taraban, & McDonald, 1989).

Infant studies have shown that prelinguistic infants are able to learn segmentation using a variety of information that is available in the speech stream. For example, the patterning of strong and weak syllables has a substantial effect on a young listener's ability to detect words. A "trochaic" bias (a preference for words with a strong syllable followed by a weak syllable) is a well-documented early sensitivity in English-speaking infants as young as 9 months old (Jusczyk, Houston, & Newsome, 1999).

As before, the reviewed study could be seen as supporting both Nativist and Emergentist perspectives. Although the trochaic bias is a characteristic of the input directed to infants, it cannot be ruled out that infants have an inherent sensitivity to this bias. The Emergentist leanings of the authors are evident from their focus on the rich acoustic cues available in the speech input directed to infants. For example, the authors cited evidence (Jusczyk, Culter, & Redanz, 1993; Vihman, De Paolis, & Davis, 1998) that (a) children younger than 6 months did not evidence this preference, and (b) the ratio of trochaic productions made by infants was directly related to the ratio of input with a trochaic bias in both English and French, suggesting the trochaic bias is at least partly emergent. This study supports the Prelexicalist contention that the speech signal contains acoustic cues that can be used for prelexical segmentation.

Addition acoustic cues in the speech stream that are useful for segmentation include lexical stress and phonotactics (Peters, 1983). Absolute phonotactics are the sequential constraints that operate on contiguous items (e.g., "str" can begin a word, such as in "straw," but cannot end a word). Probabilistic phonotactic constraints are the likelihood that certain items would be contiguous within a word or across words (e.g., "nd" is more likely to end a word, such as in "and", than to occur across words, such as in "can do"). Both absolute and probabilistic phonotactic constraints can be used for segmental purposes (Cairns et al., 1997). Emergentists propose that children can use absolute and probabilistic phonotactic constraints to develop segmentation strategies.

Cairns et al. (1997) presented evidence that a trained computer was able to predict word boundaries based on probable and absolute phonotactics. The authors argued that sequential dependencies between phoneme sequences in spoken English allowed identification of word boundaries because of absolute and probabilistic phonotactic constraints. Results of their computer model provided evidence that bottom-up cues could be used successfully for segmentation. As the model was moderately accurate at segmenting words from the speech stream, the authors claimed that sensitivity to phonotactic information represented a viable part of a wider developmental model of speech perception (Cairns et al., 1997).

Similarly, Christiansen, Allen, and Seidenberg (1998) produced a modified computer model of word-boundary prediction. They inputted continuous speech into a computer model to determine if it could discover word boundaries based on absolute and probabilistic phonotactic constraints. Their computerized model demonstrated many patterns reflecting infant behavior including a bias for trochaic stress patterns, prediction of word boundaries, and an ability to distinguish between phonotactically legal and illegal words.

Evidence of the studies reviewed so far suggest that infants are capable of using prelexical segmentation cues because of their early preferences and sensitivities and because of the rich segmental information present in the acoustic signal. The experiments discussed below demonstrate that infants are not only capable of using pre-lexical segmentation rules, but actually do use them to successfully learn new words.

A study of vocabulary comprehension by Woodward et al. (1994) suggested that children were able to use prelexical cues to segment and comprehend novel vocabulary words from naturalistic phrases ("see the *tomar*") at 13 months of age. The children were able to learn the new word after hearing it in an experimental setting nine times within a 5-minute time period. This finding suggested that preverbal infants were able to use prelexical segmentation to segment and learn the new word.

Curtin, Mintz, and Christiansen (2005) investigated the ability of 7- and 9-month-old infants to use stress as a cue to segment speech. In their study, English infants heard a recorded stream of nonsense CV syllables over and over during the learning phase of the experiment. Every third syllable in the stimulus was stressed (e.g., Pa

[stressed] Ba Da Ga [stressed] ka na). During the test phase, the authors found that infants demonstrated preferential looking for nonsense words with no stress (Pa Ba Da) or medial stress (Pa Ba (stress) Da) as compared to nonsense words with the expected initial stressed syllable (e.g., Pa [stressed] Ba Da). These results suggested that 7- and 9-month-old infants were able to use stress information to segment "words" within a presented phrase.

Similarly, Saffran (2001) conducted a study with 8-month-old children exposed to a continuous stream of nonsense words without stress or intonation cues during the learning phase (e.g., *pabiku, tibudo, golatu, daropi*). In the testing phase, nonsense words from the learning phase (e.g., *pabiku*) and noncompatible words that had not been presented in the learning phase (e.g., *tudaro*) were inserted at the end of a naturally produced English sentence and presented to the children. Saffran found that children preferred to listen to the sentences containing familiar nonsense words over the sentences containing noncompatible words. This finding suggested that they were able to use phonotactic constraints to detect nonsense word boundaries. Additional studies have also demonstrated an ability to segment speech using stress in 7- and 9-month-olds (Thiessen & Saffran, 2003), and using prelexical phonotactic and allophonic cues in 7-month-olds (Thiessen & Saffran, 2003), 9- and 10 1/2-month-olds (Mattys & Jusczyk, 2001), and 12-month-olds (Johnson, Jusczyk, Cutler, & Norris, 2003).

Reliance on the use of a prelexical segmentation strategy is reflected by slow and gradual initial word learning in infants, often requiring hundreds of repetitions of a word before learning it (Woodward et al., 1994). Reliance on the use of a prelexical segmentation strategy is also seen in slow and gradual initial word learning in computer model studies. For instance, Cairns et al. (1997) speculated that a child would need to hear many repetitions of words and plentiful, clear speech input in order to generate segmentation rules based on absolute and probabilistic phonotactics. Interestingly, this speculation is consistent with developmental literature about how young children acquire words before the vocabulary spurt (Bates et al., 1994).

In computer-modeling and adult segmentation studies, bottom-up segmentation cues alone did not always segment the speech stream into words reliably. In ambiguous cases, decisive segmentation was achieved only when the speaker utilized lexical knowledge (Christiansen & Chater, 2002). This paper postulates that the vocabulary spurt occurs in conjunction with the development of a segmentation system that efficiently integrates both lexical and prelexical cues.

Lexical Segmentation

Lexicalists argue that accounts of spoken word recognition must incorporate mechanisms by which lexical identification can contribute to the segmentation process. Research has shown that adult listeners demonstrate advanced and efficient segmentation of the speech stream using both prelexical and lexical cues. Cairns et al. (1997) reported that segmentation cues such as acoustic juncture markers, metrical cues, and phonotactic constraints need to be augmented by the introduction of lexical knowledge to optimize the segmentation system.

The Lexical perspective is often modeled as an interactive account of segmentation. An interactive model of segmentation allows the top-down influence of higher-level information on lower-level processing, or prelexical processing (Cairns et al., 1997). The discovery of word boundaries may be accomplished through routes that utilize both prelexical and lexical information (Christiansen & Chater, 2001). Lexical access models allow listeners to identify words as soon as enough information is available to distinguish them from all other words with the same onset (*e.g., cap*tain vs. *cap*ture). Cairns et al. reported that as spoken phonemes of a word are perceived over time, the words that are incompatible with the input are eliminated until only the word most likely to be appropriate for the context remains. The stored lexical phonology of the one remaining word specifies its offset. According to Lexicalists, lexical segmentation is a by-product of both top-down word recognition and bottom-up, phonemic cue recognition.

In support of an interactive segmentation account, Gow and Gordon (1995) reported that words are identified before their offset approximately 40% of the time. The other 60% of the time, participants showed word recognition after a portion of the next word had been revealed. The authors also reported that adult listeners typically recognized a noun and the preposition preceding the noun at the same time. Their results suggested that listeners most likely required acoustic information found at word boundaries in addition to lexical information in order to correctly segment words.

Christiansen and Chater (2001) reviewed experiments where adults were asked to segment degraded speech (e.g., adults heard "I see a *ird"). Christiansen and Chater argued bottom up-segmentation cues alone would not always segment the speech stream into words. They proposed that word recognition incorporating top-down input may result in a decisive segmentation in ambiguous cases. They concluded that the adult listener appears to benefit from both prelexical and lexical strategies used jointly. Both levels of processing could be enlisted in a coordinated manner depending on the informativeness of the context, task and attention demands, and noise in the signal.

The research evidence reviewed above indicates that adults use a sophisticated segmentation system and the amount to which an adult listener must rely on prelexical or lexical cues depends on the quality of the speech signal. Cairns et al. (1997) suggested that adults and children differ in the amount to which they rely on prelexical cues for segmentation. Cairns et al. proposed that young

children rely predominantly on prelexical cues to segment speech because of their limited lexicons. In contrast, adults appear to rely to a lesser degree on acoustic cues and can distinguish words in a sentence even if parts of the acoustic signal are missing or distorted (Christiansen & Chater, 2001). Gow and Gordon (1995) reported that variations in amplitude and pitch did not affect adult listeners' segmentation performance.

The hypothesis of this paper is that children transition from the use of an immature segmentation system using predominantly prelexical cues to an increasingly sophisticated, integrated segmentation system incorporating both prelexical and lexical cues. Importantly, the results of two recent studies suggest that infants may use their limited lexical knowledge for segmentation before speaking their first words (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Kooijman, Hagoort, & Cutler, 2005). Although some lexical segmentation strategy use may occur earlier, this paper postulates that an infant's segmentation system undergoes a qualitative change after the child has acquired a small vocabulary (approximately 50-150 words). This qualitative change in segmentation efficiency is observable by an increased ability to segment and learn new words (fast mapping), and is associated with the onset of the spurt in vocabulary acquisition.

An Integrated Segmentation System

Davis et al. (2002) presented an hypothesis about how prelexical acoustic information can assist in lexical access so that the two systems can work together for successful segmentation. They conducted several experiments in which the response times of adult listeners to short-word and long-word options (e.g., *cap* vs. *captain*) were recorded. They found reliable differences in the articulation of syllables in short and long words. Results provided confirmation that the activation of short and long lexical items was biased by acoustic cues that differentiated short words from the initial syllables of longer words. Davis et al. concluded that additional cues are presented in the speech stream that assist the perceptual system in distinguishing short words from the longer competitors within which they are embedded. Results of this study suggested that lexical access was more efficient when integrated with prelexical cues.

Similarly, Gow and Gordon (1995) proposed an interdependence of prelexical cues and lexical knowledge for speech stream segmentation. They used a priming technique to determine which word meanings adult listeners accessed after hearing oronyms (e.g., *two lips* and *tulips*) in connected speech. Their results suggested that listeners simultaneously accessed the meanings of words associated with several parses of lexically ambiguous phoneme sequences (e.g., *two, tool, tulip, lip*). They concluded that the success of lexical access depends on subtle prelexical characteristics of how words are pronounced. Gow and Gordon suggested that lexical access is initiated continuously; however, the dominant input to lexical access is the acoustic, prelexical marking and intelligibility of word onsets. Their results indicated that lexical segmentation by children or adults appeared to be most effective when used in conjunction with bottom-up, prelexical cues.

Mattys and Jusczyk (2001) conducted an experiment investigating the development of an integrated system of interactive lexical and prelexical segmentation abilities in 8- and 16-month-old infants. Using a preferential-looking, head-turning paradigm, they repeatedly exposed infants to sentences with the words "cash" and "dice" embedded in them. They then presented infants with the choice of "pack ash" or "cleared ice" vs. "cash" or "dice" to determine if infants successfully segmented the words or were simply listening for familiar sound sequences. At 8 months, infants were not able to segment vowel consonant (VC) words (ice, ash) from fluent speech; however, 16-month-olds who had acquired some vocabulary words were able to segment the VC targets of the passages. Results from this study support the proposal of this paper, that only after infants have acquired a small lexicon are they able to engage both prelexical and lexical segmentation strategies in an integrated manner.

Evidence from the above empirical studies seems to suggest that the integration of prelexical and lexical types of information is necessary for efficient segmentation. Mattys and Jusczyk's study presents preliminary evidence supporting the proposal of this paper, that an integrated segmentation system does not develop until after a small lexicon is acquired. Similarly, Marchman and Bates (1994) and Plunkett (1998) reported that listeners appear to enlist both prelexical and lexical information, but are able to do so only after acquiring a "critical mass" of lexical items through bottom-up segmentation. Importantly, Mattys and Jusczyk's (2001) study places the development of an integrated segmentation system on a timeline compatible with the onset of the vocabulary spurt, indicating an association between the two phenomena.

The Vocabulary Spurt

The vocabulary spurt occurs when the rate at which children acquire new words begins to increase exponentially rather than linearly (MacWhinney, 1998). It occurs with an enormous amount of individual variation (Bates, Dale, & Thal, 1995; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). Mervis and Bertrand (1995) assessed the vocabulary size of 3 children by parent report on a weekly basis. Their results suggested that many normally developing children evidence a spurt when vocabulary size is between 50 and 150 words. Nouns are predominantly added (three quarters of new words) to increase the vocabulary for many children (Goldfield & Reznick, 1990; Plunkett, 1998).

Fenson et al. (1994) compiled lexical acquisition data by parent report for 1,803 children between 8 and 30 months of age. They found a wide variability across children in the time of onset and course of lexical

acquisition. Their results confirm findings of older studies indicating that vocabulary growth curves demonstrated a "spurt" after the acquisition of between 50 and 150 words (Benedict, 1979; Bloom, 1973; Dromi, 1986; Goldfield & Reznick, 1990; Nelson, 1973). This effect was most obvious for children above the 50th percentile in terms of expressive vocabulary development.

Many explanations have been put forward for the vocabulary spurt (Cicchetti, 1993), including the development of object permanence and object categorization (Gopnik & Meltzoff, 1984; Woodward et al., 1994) and increased control of articulation (Schwartz & Leonard, 1981; Schwartz, Leonard, Frome Loeb, & Swanson, 1987). Although development in other areas may play a role, it is the proposal of this paper that the development of an integrated system to segment words from continuous speech is also associated with the onset of the vocabulary spurt.

Integrated Segmentation as a Precursor to the Vocabulary Spurt

In their review, Nazzi and Beroncini (2003) reported that prior to the spurt an infant's lexicon contains "proto-words" corresponding to the pairing of a phonetically underspecified, prelexic, acoustic sound pattern and an object (e.g., *num num* refers to a cookie). Genuine words appeared with the vocabulary spurt and were acquired by pairing a phonetically specified sound pattern to an abstract lexical concept, a top-down cognitive operation (e.g., *dog* refers to a canine). Their study supported the proposal of this paper that the vocabulary spurt is associated with the development of an integrated prelexical and lexical acquisition mechanism for segmentation.

Fernald, Pinto, Swingley, Perfors, Magnani, and Bradley (1998) assessed the ability of 15- and 24-month-old children to initiate eye movements toward a named picture. They found that 15-month olds did not initiate eye movement toward the picture until after the offset of the spoken word. In contrast, 24-month olds responded before offset of the word. The results of this study suggested that younger children required prelexical cues to determine where the word began and ended and were unable to use lexical knowledge. Older children made decisions about word identity based on only partial phonetic information, indicating that they were able to use lexical knowledge for segmentation. These findings were in agreement with Mattys and Jusczyk's (2001) study (see above). Both authors found that children younger than 16 months of age did not appear to be able to use lexical information to aid in segmentation while children 16 months and older were able to use such cues. Importantly, it should be recognized that the ages at which children achieve these milestones will vary a great deal (Bates et al., 1995; Fenson et al., 1994) and may also depend on the sex of the child (Fernald, Swingley, & Pinto, 1998).

In a follow-up study, Fernald, Swingley, et al. (1998) assessed the ability of 21-month-olds to initiate eye movements toward a named picture when the picture names were truncated (e.g., *ba* for *baby* or *ki* for *kitten*). Infants with precocious language skills (mostly girls) were able to perform this task accurately, while less precocious infants (mostly boys) were not. The results of Fernald and colleagues' two studies indicated that (a) children at 15 months of age or younger still rely predominantly on prelexical segmentation strategies, (b) children between the ages of 16 and 21 months are just learning how to integrate lexical knowledge into their prelexical segmentation system, and (c) children at 24 months of age are progressing toward the highly efficient segmentation performance of adults and are able to use prelexical and lexical cues for segmentation. Importantly, infants make dramatic gains in their ability to segment familiar words from the speech stream toward the end of the second year. The development of this skill appears to coincide with and may prove to be important for the vocabulary spurt.

Segmentation Preferences and the Vocabulary Spurt

En route to use of a joint prelexical-lexical segmentation strategy, children often employ non-standard, undershooting segmentation strategies, which do not possess the full target lexical unit (MacWhinney, 1987; MacWhinney et al., 1989). For example, they may use a schwa as a "filler word" to take the place of a morpheme or word in a phrase (e.g., *sleep-uh* instead of "sleeping," or *He uh big* instead of "He is big"). Undershooting represents an overemphasis on prelexical segmental strategies where children pay strict attention to word boundaries within a phrase and use filler words to mark the place of words they have not yet learned.

Children may also ascribe lexical status to whole sequences of words, called overshooting (MacWhinney et al., 1989). Overshooting represents an overemphasis on lexical segmentation strategies, where children attempt to ascribe abstract, conceptual meaning to a string of sounds (e.g., "Gotcha" or "Whassat?"). Overshooting also represents an inappropriate de-emphasis of prelexical segmentation strategies so that the acoustic cues indicating word boundaries are ignored.

Over- and undershooting may be indicators of the problem-solving process children go through in an attempt to integrate prelexical and lexical segmentation strategies into one segmentation system. Research conducted by Plunkett (1993) presents evidence to suggest that the vocabulary spurt appears to be associated with the successful integration of lexical strategies to the existing prelexical strategies. Plunkett (1993) conducted a case study of two children who evidenced unique approaches to segmentation and lexical acquisition. He made a detailed analysis of the children's utterances for overshooting and undershooting. He found that both children underwent a period of experimenting with

undershooting and overshooting before exhibiting a vocabulary spurt between 19 and 21 months of age. Both undershooting and overshooting diminished substantially immediately following the vocabulary spurt.

Plunkett concluded that the profiles of vocabulary development for the two children suggested that a qualitative change in segmentation strategy might have been an important trigger for their vocabulary spurts. His study provided support for the hypothesis of this paper, that the timing of the vocabulary spurt coincides with, and may be partially determined by, the merging of prelexical and lexical segmentation strategies into one cohesive system.

Bates et al. (1994) proposed that children varied in their preference for using either the overshooting or undershooting segmentation strategy. Children labeled as "referential" in their experiment demonstrated relatively more undershooting errors. Referential children relied a great deal on prelexical cues for segmentation and tended to use filler words as place markers for not-yet-learned words. Children labeled as "holistic" demonstrated more overshooting. Holistic children tended to ignore prelexical cues indicating word boundaries and gave a lexical meaning to phrases instead of single words. Bates et al. found that children's preference of segmentation strategy was associated with qualitative variations in the speed and order of vocabulary acquisition. In their study, which documented the language acquisition of a group of 1,803 children between 8 and 30 months of age, they found that holistic children (overshooters with a lexical segmentation strategy preference) reached a vocabulary spurt with open class words much later than referential children (undershooters with a prelexical segmentation strategy preference) (Bates et al., 1994).

Confirming results by Bates et al. (1994), D'Odorico, Carubbi, Salerni and Calvo (2001) analyzed vocabulary acquisition data for 42 Italian children and found that a holistic learning style was associated with a slower rate of lexical development. Similar results were found in an earlier study by Nelson (1973). Nelson found that holistic children acquired a 50-word vocabulary weeks or months later than referential children.

The Role of Vocabulary Comprehension

Another reason that children may use a holistic versus a referential style may be due to differences in their vocabulary comprehension abilities. Vocabulary production and vocabulary comprehension are highly interdependent processes. Although speculative, vocabulary comprehension may influence segmentation in several ways. For example, advanced vocabulary comprehension could aid in the transition to and use of lexical strategies in an integrated segmentation system. It is also possible that children with less advanced vocabulary comprehension may rely on the overall intonation or "melody" of the message to determine the speaker's intention rather than trying to analyze the meanings of individual words.

Reviewed Studies: A Summary and Some Limitations

A review of acoustic studies of infant-directed speech revealed the presence of an abundance of acoustic cues present in the speech signal, and particularly in motherese, that can be used to reliably segment the speech stream. Two of these cues were volume and word position (Messer, 1981). Other cues included stress pattern (Jusczyk et al., 1999), clausal pauses (Hirsch-Pasek et al., 1987), and probabilistic phonotactic constraints (Cairns et al., 1997). A limitation of these studies is that is that the majority of them are conducted with English-speaking children and these cues may not be universal across languages (e.g., word order, stress pattern). However, Bates et al. (1994) reported that infants appear to be sensitive to the information values of cues in their native language.

Reviewed studies of infant behavior revealed infant listening preferences for aspects of acoustic input that may help the infant segment the speech stream. For example, infants demonstrated a preference for listening to spoken language in general (Baldwin & Markman, 1989), the exaggerated prosodic stress of motherese (Cooper & Aslin, 1999), and natural clause boundaries within motherese utterances (Hirsch-Pasek, et al., 1987). It is not yet known, however, to which particular aspects of the acoustic signal the infant is responding. Neither has research been able to conclusively determine that infants are responsive to segmental cues specifically (Baldwin & Markman, 1994).

Both preverbal children (Curtin et al., 2005; Johnson et al., 2003; Mattys & Jusczyk, 2001; Saffran, 2001) and adults (Gow & Gordon, 1995) make use of prelexical cues present in the acoustic signal to find word boundaries. A review of the literature also presented evidence that older children and adults (Christiansen & Chater, 2001) make use of lexical knowledge to identify individual words within the speech stream. These two strategies appear to be integrated during development, and there is some evidence regarding the age range (between 16 and 21 months) at which this integration occurs (Fernald, Pinto, et al., 1998; Fernald, Swingley, et al., 1998; Mattys & Jusczyk, 2001). What remains unknown is how these particular segmentation systems work together and which (if any) system acts as the dominant system at a particular developmental stage or for a particular listening situation.

The current proposal is that the development of an integrated segmentation system is associated with the onset of the vocabulary spurt. The evidence for this proposal can be considered promising, but preliminary because these studies were (a) limited in number, (b) cross-sectional rather than longitudinal, and (c) not specifically designed to examine the relationship between segmentation and the vocabulary spurt.

Alternative Hypotheses

The current paper proposes an association between the development of an integrated segmentation system and the onset of the vocabulary spurt. Several interpretations of the nature of this association are possible. The interpretation favoured both by this paper and by Plunkett (1998) is that integrated segmentation is an important foundation skill (perhaps one of many) that facilitates lexical acquisition. This hypothesis has not been directly tested to date, but is based on two lines of indirect evidence presented in the current paper. First, integrated segmentation appears to immediately precede the vocabulary spurt (Fernald, Swingley, et al., 1998; Mattys & Jusczyk, 2001), and second, preferences for prelexical vs. lexical segmentation strategies appear to be correlated with differential timing of the onset of the vocabulary spurt (Bates et al., 1994; D'Odorico et al., 2001; Nelson, 1973).

Alternative interpretations of the relationship between the vocabulary spurt and the development of an integrated segmentation system are also possible. For example, these two phenomena may be related in time, but with no causal relationship between them. It is also possible that both the vocabulary spurt and integrated segmentation may result from a common underlying developmental achievement, or each may result from development in different areas (e.g., cognition, pragmatics, articulation). Alternatively, the vocabulary spurt may facilitate the development of an integrated segmentation system, because of the increase in lexical knowledge. The validity of these alternatives needs to be evaluated in future investigations directly assessing this association.

Although the data so far are congruent with the proposed association between an integrated segmentation system and the vocabulary spurt, at this time, the data remain inconclusive as to the nature of this relationship. Further research that directly tests this model is needed to clarify this issue. Such research is warranted, given the indirect evidence presented in the reviewed studies.

Clinical Implications

Explanations about segmentation can be a valuable part of parent education. It should be explained to parents of children who are late talkers what a difficult task it is to segment speech from a continuous speech stream. This information may motivate parents to emphasize prelexical word-boundary cues to help their children segment speech (e.g., slower rate, shorter sentences, pausing, altered volume, stress, and pitch). Research has shown these types of strategies are effective in improving early language skills (Barnes, Gutfreund, Satterly, & Wells, 1983; Messer, 1981; Peters, 1985; Murray, Johnson, & Peters, 1990;).

Prelexicalists agree that infants are sensitive to acoustic cues of speech. This means that even very young infants can benefit from exposure to speech. Although parents know that infants understand only a small percentage of what they say, parents can be made aware that even very young children will learn more about how to segment words from speech the more they hear it.

Discovery of the use of overshooting and undershooting by children during assessment may be an early indicator of the upcoming vocabulary spurt and serve to allay parents' concerns about delayed vocabulary development. Analysis of a child's segmentation strategy preference may serve as useful assessment information. Undershooting, or a referential style in particular, may indicate that a child is successfully marking word boundaries and that an earlier vocabulary spurt and precocious language acquisition is likely.

Conclusion

The evidence from studies of lexical acquisition and segmentation development (particularly those by Fernald, Pinto, et al., 1998, and Fernald, Swingley, et al., 1998) suggests that after children develop a critical mass of approximately 50-150 lexical units, their segmentation system appears to undergo a qualitative change. This change entails a newly developed ability to coordinate prelexical and lexical segmentation processes (Mattys & Jusczyk, 2001), is more efficient than the preexisting system, and appears to coincide with the emergence of children's vocabulary spurt.

The proposal of this paper differs from other theories about the importance of segmentation to the vocabulary spurt (Fernald, Swingley, et al., 1998; Plunkett, 1993) because this paper presents evidence that the segmentation system undergoes a transition from an inefficient system relying on prelexical segmentation cues to a sophisticated system integrating both lexical and prelexical cues. The results of several research studies are highlighted (Fernald, Pinto, et al., 1998; Fernald, Swingley, et al., 1998; Mattys & Jusczyk, 2001) to demonstrate how and when this transition develops in children. This postulation is also unique because it specifies that this transition to a more sophisticated segmentation system co-occurs with the acquisition of a critical mass of lexical items. Evidence to support this hypothesis is sufficiently compelling to justify additional studies investigating segmentation abilities in children and the onset of the vocabulary spurt.

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