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Overcoming the Effects of Variation in Infant Speech Segmentation: Influences of Word Familiarity

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Abstract

Previous studies have shown that 7.5-month-olds can track and encode words in fluent speech, but they fail to equate instances of a word that contrast in talker gender, vocal affect, and fundamental frequency. By 10.5 months, they succeed at generalizing across such variability, marking a clear transition period during which infants' word recognition skills become qualitatively more mature. Here we explore the role of word familiarity in this critical transition and, in particular, whether words that occur frequently in a child's listening environment (i.e., "Mommy" and "Daddy") are more easily recognized when they differ in surface characteristics than those that infants have not previously encountered (termed nonwords). Results demonstrate that words are segmented from continuous speech in a more linguistically mature fashion than nonwords at 7.5 months, but at 10.5 months, both words and nonwords are segmented in a relatively mature fashion. These findings suggest that early word recognition is facilitated in cases where infants have had significant exposure to items, but at later stages, infants are able to segment items regardless of their presumed familiarity.

To master their native language, young learners must translate words they encounter into meaning. Although the mechanisms that permit word learning remain unclear, children begin to successfully learn words at a very early age, with word comprehension beginning as early as 10 months (Benedict, 1979) and a productive vocabulary shortly thereafter (Nelson, 1973). This process might appear uncomplicated, given how effortlessly infants appear to learn words, but there are quite weighty demands that they must meet before word learning can begin. Two of the most widely documented challenges a young learner confronts are the segmentation and variability problems. *Segmentation* refers to the fact that speech unravels as a continuous stream without convenient pauses inserted between words, making it incumbent on listeners to partition the signal appropriately (Jusczyk, 1997; van de Weijer, 1998). *Variability* refers to the fact that human speech contains acoustic information that does not signal linguistic distinctions. How our systems converge on constancy from inordinate variability remains a mystery in every domain of perception. In the domain of speech, learners must compose a finite phonetic and lexical inventory from a complex stream of input that varies substantially and, therefore, unpredictably.

Infants' capacities to resolve the segmentation and variability problems have been investigated over the last 10 years. In a seminal study, Jusczyk and Aslin (1995)

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demonstrated that infants recognize words in fluent speech by 7.5 months, several months before they have discovered the meanings of those words. Although this represents a startling ability at an unexpectedly young age, the fact that infants have not yet attached meaning to words is reflected in the fragility of their memories. For example, Jusczyk and Aslin (1995) and others (Barker & Newman, 2004; Houston & Jusczyk, 2000; Jusczyk & Hohne, 1997) have shown that infants retain memories of words reliably and enduringly but their abilities are circumscribed by the physical similarity shared across different encounters of a word. For example, at 7.5 months, infants fail to equate instances of the same word when familiarized with a token spoken by a male speaker and then later by a female speaker (Houston & Jusczyk, 2000). Similarly, infants falter when familiarized with a word spoken in positive affect and then later in neutral affect (Singh, Morgan, & White, 2004). Even when words are manipulated along spectrally simpler dimensions, such as fundamental frequency, 7.5-month-old infants fail to recognize words across encounters (Singh, White, & Morgan, in press). Of course, these limitations are temporary and infants come to recognize words even in the face of changes in talker gender, fundamental frequency, and vocal affect by 10.5 months (Houston & Jusczyk, 2000; Morgan, 2002; Singh et al., 2004).

Therefore, the period from 7.5 to 10.5 months represents a watershed in language development where infants progress from strictly episodic to more abstract word recognition abilities. The time course of this transition suggests that infants' capacity to resolve problems of variability awaits their resolution of the segmentation problem. However, thus far, infants have been tested on their capacities to resolve the segmentation problem and the variability problem in an input environment that does not fully approximate the diversity of natural input. Specifically, infants have been tested on four monosyllabic words, all deemed to be unfamiliar to them. Such measures were put in place for good reason, namely to control for prior exposure to words outside of the laboratory. However in natural discourse, caregivers certainly do not treat all words equally, disproportionately emphasizing some words in their speech to infants more than others and incorporating no controls such as those present in the laboratory. For example, a small class of words that might receive particular emphasis across households consists of the infant's own name, names for siblings, and finally, monikers for the infant's parents. By investigating spoken word recognition using items such as these, it should be possible to reveal more nuanced abilities on the part of infants to segment words and also, to equate varying forms of the same word. Therefore, it is possible that familiarity with items assists the resolution of both the segmentation problem and the variability problem.

The theoretical motivation for this investigation derives from a lack of clarity as to why infants demonstrate fragility in early word segmentation and how they evolve beyond this stage in preparation for vocabulary development. Clearly, infants do transit to a stage where word recognition is more robust and reflects a more abstract level of processing. However, it is unclear what factors might facilitate this process other than maturation. One strong possibility explored here is that word recognition is heavily mediated by the nature of an infant's prior experience with the specific items involved. Words vary tremendously not simply in their frequency in the input, but also in the extent to which they cooccur with meaning, and in their inherent significance for infants. This results in a linguistic environment that represents individual lexical items in unequal measure. The rationale behind this investigation is therefore to determine how the inevitable inequities in familiarity with words influence emerging word knowledge.

There might be several defining characteristics of familiarity in the input. First, it is possible that the reason certain items quickly become familiar to infants, such as the moniker for a child's parents, is that these words carry social-emotional significance for infants as they refer to sources of care and nourishment. It might serve a developing infant well to identify and recognize these words in the input above others. A second potential correlate of familiarity is statistical overrepresentation, whereby certain words are simply presented to infants more frequently. Such words are possibly processed more efficiently or accurately. In other words, they might benefit from the types of frequency effects previously reported with highly frequent phonotactic patterns and stress patterns (Jusczyk, Houston, & Newsome, 1999; Mattys & Jusczyk, 2001) whereby common (and therefore, familiar) sequences are encoded and retrieved more effectively than uncommon sequences. Finally, word familiarity might have a referential component, where highly familiar words have undergone semantic analysis by infants. A common observation in child-directed speech, for example, is the tendency for parents to refer to themselves in the third person rather than in the first person, a style of communication that might facilitate early mapping of these words to their meanings. There is evidence that infants map monikers for their parents onto meaning quite early in development at 6 months (Tincoff & Jusczyk, 1999), suggesting that word-to-meaning mappings for these items might precede that of most other items. Each component of familiarity is probably not independent and in all likelihood, they are conflated. For example, many familiar items, such as *Mommy* and *Daddy* are probably familiar for each of the aforementioned reasons, including high social-emotional significance, statistical overrepresentation, and semantic transparency (i.e., used in regular cooccurrence with meaning), suggesting that the basis for any advantage of these items in language development is likely to be multifactorial.

There have been several initiatives to determine whether there are learning benefits attached to highly frequent words. Indeed, an investigation of word learning has revealed that infants can map the word *Mommy* onto their own mother, and the word *Daddy* onto their own father by 6 months (Tincoff & Jusczyk, 1999), several months before novel word learning is underway. Furthermore, the inclusion of words such as the child’s own name and *Mommy* and *Daddy* in speech has been shown to facilitate the segmentation of neighboring words by establishing word boundaries for young learners (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005). Finally, in terms of their listening preferences, infants have an attentional bias to such words, preferring to listen to their own names compared with stress-matched foils as early as 4.5 months (Mandel, Jusczyk, & Pisoni, 1995).

Collectively, these findings suggest a privileged status attached to such words in tasks that measure segmentation of neighboring words, mapping words to meaning, and infants’ allocation of attention. This study seeks to determine whether these words are also privileged in how infants cope with variability in speech. This poses a broader question of how infants learn to cope with variability and whether word familiarity (regardless of whether the basis for familiarity is lexical, statistical, or emotional) contributes to the identification of phonological invariants. For example, if a learner detects that the word *Mommy* can assume different physical manifestations, all the while referring to his or her mother, it is possible that this detection of phonological invariants could generalize to other words, indicating a rule-governed mechanism by which acoustic–phonemic correspondences are induced. Indeed, recent research by Singh (in press) has demonstrated that when 7.5-month-old infants are taught that surface changes are not relevant to vocal identity for a particular word (e.g., *bike*), that knowledge does appear to generalize to other words (e.g., *hat*) for which such information is not explicitly provided. Therefore, it is possible that knowledge of form–meaning correspondences for frequent words might aid such knowledge of nonfrequent, novel words.

In our first experiment, we seek evidence of word segmentation in 7.5-month-olds amidst surface variability, manipulating word familiarity and surface form (i.e., fundamental frequency). In doing this, we hope to discover whether the capacity to segment words amidst variation in pitch is facilitated by familiarity with words, and whether infants demonstrate limited abilities independent of word familiarity. In our second experiment, we are concerned with how older infants fare in segmentation tasks when these factors are manipulated. Have older infants previously demonstrated more robust segmentation because they have become familiar with the words often used in the experimental setting as stimuli, such as *cup* and *feet,* or do they have more robust abilities independent of word familiarity? Finally, is there an effect of age in how novel words are treated when those words vary in surface form and is the transition from 7.5 to 10.5 months associated with more abstract recognition of all words, or primarily of novel words? Therefore, the overall objective of these studies is to examine interactions of age, word familiarity, word segmentation, and surface variability to acquire a fuller understanding of how word segmentation evolves and matures in a way that primes an infant for mapping words to meaning.

EXPERIMENT 1

In this experiment, we manipulated a dimension of sound that varies commonly in infant-directed speech (IDS), fundamental frequency (F0), which has been shown to interfere with word recognition at this age (Singh et al., in press). Using a procedure pioneered by Jusczyk and Aslin (1995) to measure word segmentation and recognition, we investigated how word familiarity interacts with speech segmentation and the presence of surface variation, hypothesizing that familiarity with a word might strengthen relatively young infants' capacities to recognize the word even amidst surface variation at an age when infants typically cannot recognize unfamiliar words that differ in surface form.

Participants

Thirty-two English-exposed 7.5-month-olds participated in the study (14 boys and 18 girls), recruited from Massachusetts birth records and advertisements. Mean age of participants was 234 days (range = 213–244 days). Data from 1 additional infant were not included due to inattention. Parental reports verified that *Mommy* and *Daddy* were commonly used in speech directed to the infant.Stimuli

Stimuli were created by manipulating IDS produced by a female speaker. The pitch manipulations were carried out using Praat (Boersma & Weenink, 2002) in a manner identical to those conducted in preceding studies (Singh et al., in press). One set of familiarization stimuli was created by increasing the fundamental frequency of all naturally produced stimuli by one-quarter octave. This was done by applying a uniform translation of all pitch points up by one-quarter octave. A second set of stimuli was created by decreasing the fundamental frequency of all stimuli by the same amount (one-quarter octave). Therefore, the difference between the two sets of stimuli was half an octave. Both sets of stimuli involved equal pitch manipulations so that infants' preferences would not be affected by the perceived naturalness of the stimuli. Acoustic analyses were conducted on all stimuli and are tabulated in Table 1. As planned, high-pitch stimuli were significantly elevated in mean F0 compared with low-pitch stimuli, $t(14) = 4.96$, $p < .05$, $\eta 2 = .64$. There were no significant differences between high-pitch familiarization words and recognition passages and low-pitched familiarization words and recognition passages, suggesting that the stimuli were pitch-matched. In previous research using the same pitch manipulations (Singh et al., in press), 7.5-month-old infants were unable to recognize novel familiarized words such as *bike* and *hat* differing in pitch by the same interval.

Procedure

Infants were tested using the Headturn Preference Procedure (HPP; Kemler Nelson et al., 1995), which was implemented identically to previous studies (Bortfeld et al., 2005; Jusczyk & Aslin, 1995; Singh et al., 2004; Singh et al., in press). The infant was seated on the parent's lap facing a center light. Each trial began with the center light flashing until the infant fixated on the flashing light. Then this light was turned off, and one of two side lights began to flash to attract the infant's attention. When the infant fixated on the side light, speech stimuli for that trial began to play. The sound and light remained on for the duration of the infant's fixation.

Familiarization began with trials alternating between the two target words until 30 sec of familiarization had accrued for each word. Recognition testing consisted of four blocks of trials, each block containing one trial with each of the four passages. The order of passages within each block was randomized for each infant, as was the order of sentences within passages on each trial.

During familiarization, infants heard repetitions of two different items. One item was a highly familiar bisyllabic word (either *Mommy* or *Daddy*), hereafter termed words. The other was a stress-matched item (*Luka* or *Ghana*) that was unfamiliar (i.e., not known to infants prior to entering the laboratory). These unfamiliar items are termed nonwords. Therefore, a particular infant was familiarized with *Mommy* and *Luka* or *Daddy* and *Ghana*. During a recognition phase, infants then heard each familiarized item and two nonfamiliarized items embedded in sentences. There was one within-subjects manipulation, the pitch of the familiarization items. For all infants, one familiarization item was presented in a high pitch and one in a low pitch. There were two between-subject manipulations: the pitch of the recognition passages and the pairing of match status (matched pitch or mismatched pitch) to familiarization item (word or nonword). In the first between-subject manipulation, half of the infants heard all passages in a high pitch and half heard all passages in a low pitch. Therefore, for each infant, one familiarization item was pitch-matched across familiarization and recognition and one familiarization item was pitch-mismatched.

In the second between-subject manipulation, for one condition (Condition 1), the nonword was matched in pitch to the recognition passages and the word was mismatched. For the other (Condition 2), the word was matched and the nonword was mismatched. A summary of the experimental design and stimulus manipulations can be found in Table 2.

Words and passages are listed in the Appendix. Word recognition was indexed by the amount of time infants listened to passages containing familiarized words and to those containing nonfamiliarized words during the recognition phase.

Results and Discussion

In this experiment, the dependent variable consisted of infants' looking times to passages containing familiarized words relative to passages containing nonfamiliarized words. Recognition scores were derived by subtracting an infant's mean looking time to passages containing nonfamiliarized items from their looking time to passages containing each familiarized item. As in previous studies (Singh, in press; Singh et al., in press), a recognition score that departed significantly from zero was considered to be evidence of word recognition. This resulted in two recognition scores for each infant. Raw looking times are shown in Figure 1 for sentences containing words and nonwords and to each type of control passage (i.e., passages containing unfamiliarized words). There were no significant differences in listening times to each type of control (unfamiliar) passage. Listening times to unfamiliar passages are therefore collapsed into a single bar. Furthermore, there was no independent effect of item on listening times to recognition passages.

In our analyses, we first sought to determine in which conditions infants had recognition scores that departed significantly from zero, reflecting recognition of familiarized items. In the first condition, infants were tested on their recognition of familiarized nonwords (e.g., *Luka* or *Ghana*) that were matched in pitch, for which successful recognition was hypothesized. Infants were also tested on their recognition of familiarized words (e.g., *Mommy* or *Daddy*) that were mismatched in pitch. Given the mismatch in surface form that has been shown to thwart word recognition at this age, it was hypothesized that infants would recognize the words *Mommy* and *Daddy* by virtue of their exceptional familiarity. Planned pairwise comparisons revealed significant recognition scores for matched nonwords, such as pitch-matched *Ghana* or *Luka*, t (15) = 4.27, $p < .01$, $\eta^2 = .55$, as hypothesized. Similarly, infants showed significant recognition of mismatched words, such as mismatched *Mommy* and *Daddy*, $t(15) = 2.4$, $p < .05$, $\eta^2 = .28$. These results confirm that infants recognize familiarized words that are matched in pitch, confirming previous findings demonstrating word recognition of unknown monosyllables that are matched in pitch and extending those findings to bisyllabic items. More critically, it appears that previous familiarity with words can mitigate some of the challenges introduced by surface variation, resulting in successful word recognition for items that are presumed to be highly familiar to infants prior to their visit to the laboratory.

In the second condition, infants were tested on recognition of matched words and mismatched nonwords. Given the combination of a match in pitch and previous familiarity with words such as *Mommy* and *Daddy,* it was hypothesized that infants would listen longer to passages containing either of these words relative to unfamiliar passages. Given the challenges posed by mismatched surface form to early word recognition, it was expected that infants would not recognize mismatched nonwords at this age. Indeed, findings revealed significant recognition of familiarized words such as *Mommy* or *Daddy* in a matched pitch, $t(15) = 3.18$, $p < .01$, $\eta^2 = .40$. However, the only word type that infants did not recognize across all conditions of this experiment were nonwords such as *Luka* and *Ghana* when they were mismatched in pitch, $t(15) = .35$, *ns.*[1]

One possible caveat attached to our experimental design is that the individual items might have differential appeal. Specifically, it is conceivable that *Mommy* and *Daddy* are not equivalent in their inherent appeal or familiarity for infants. Whereas we can assume that *Luka* and *Ghana* are equally unfamiliar, it cannot be assumed that *Mommy* and *Daddy* are equally familiar. To address this, an item analysis was performed to determine any significant effects of item, revealing that those infants in the *Mommy* condition demonstrated higher recognition scores than those in the *Daddy* condition for these two items, $t(15) = 2.87$, $p < .05$, $\eta^2 = .35$. There were no other significant effects of item either in familiarization or in recognition.

Results revealed that infants at 7.5 months were able to recognize words and nonwords alike when matched in pitch. However, when familiarized items were mismatched in pitch, infants only recognized words and failed to recognize nonwords. This indicates that for words with which infants have become familiar outside of the laboratory, pitch variation no longer exerts catastrophic effects on early word recognition.

At some point, infants must be able to segment items that vary in surface form even if those words are not exceptionally familiar. Most words that infants will learn do not have the

[1]An alternative interpretation of this finding is that matched familiar words are inherently engaging and that the attentional draw of these items usurps attention that would otherwise be devoted to competing familiarization items (in this case, a mismatched nonword). The effect of this unequal distribution of attentional resources could affect listening patterns during familiarization and test alike, and could potentially account for the observed failure to recognize mismatched nonwords. A limitation of this experimental design is that it cannot eliminate or confirm this possibility. However, failed recognition of mismatched items at this age has been demonstrated and replicated in several previous investigations (e.g., Houston & Jusczyk, 2000; Singh et al., 2004; Singh et al., in press), suggesting a genuine incapacity to recognize these items at 7.5 months.

emotional significance or occur with such frequency in the input as *Mommy* and *Daddy*. Therefore, it stands to reason that infants would learn to disregard nonphonemic surface changes for words that are less familiar than *Mommy* or *Daddy* and that this capacity would be integral to the accrual of a vocabulary. Previous studies have shown that by 10.5 months, infants are less sensitive to the effects of nonphonemic surface variation in spoken word recognition for unfamiliar words (Houston, 2000; Singh et al., 2004). The goal of the next experiment was to assess the interaction of surface variation and familiarity in older infants at 10.5 months. It was hypothesized that by 10.5 months, the beneficial effects of familiarity on overcoming surface variation are neutralized by virtue of infants' discovery of the nonphonemic status of pitch in English. Furthermore, this discovery is expected to facilitate recognition of words with which infants are entirely unfamiliar outside the laboratory. Given that infants at 10.5 months are on the cusp of building a comprehension vocabulary, assessing their recognition of words with which they likely have no familiarity from outside of the laboratory will help us to determine whether abilities to overcome surface variation previously reported in this age group were primarily due to the stimuli having become familiar (and possibly even, meaningful) for some or all infants. Stimuli in previous studies such as *cup, feet, dog,* and *hat* could all plausibly feature prominently in a child's input. By testing recognition of words such as *Luka* and *Ghana* at 10.5 months, it would be possible to determine whether their abilities extend to entirely new nonwords, allowing us to speculate about whether the familiarity of these word forms (and perhaps even semantic analyses of these words) are what enabled older infants to disregard nonphonemic variation in previous studies (Houston & Jusczyk, 2000; Singh et al., 2004).

EXPERIMENT 2

In this experiment, older infants were tested on the preceding task to determine whether a complete lack of familiarity thwarts infants' resolution of surface variation in word recognition. Furthermore, we sought to determine whether word familiarity continued to facilitate the resolution of surface changes at an older age group.

Participants

Thirty-two English-exposed 10.5-month-olds participated in the study (18 boys and 14 girls), recruited from Massachusetts birth records and advertisements. Mean age of participants was 320 days (range = 306–360 days). Data from 12 additional infants were not included due to inattention ($n = 5$) and technical problems with the stimulus presentation ($n = 7$).

Stimuli, Apparatus, and Procedure

Stimuli, apparatus, and procedure were identical to Experiment 1.

Results and Discussion

As in Experiment 1, recognition scores were computed and are displayed in Figure 2. Given the identical experimental design, the planned statistical analyses conducted in Experiment 1 were conducted on these data as well. In the first condition, infants showed significant recognition scores for mismatched words, $t(15) = 4.52$, $p < .01$, $\eta^2 = .58$, as well as for matched nonwords, $t(15) = 3.07$ $p < .01$, $\eta^2 = .39$. These results are comparable with those from the corresponding condition of Experiment 1 where word recognition is successful when items are matched in pitch or when they are highly familiar.

In a second condition, infants were presented with matched words and mismatched nonwords. In this condition, planned comparisons assessing the departure of recognition scores from zero revealed significant recognition scores for matched words, $t(15) = 3.49$, p

$< .01$, $\eta^2 = .45$, as well as for mismatched nonwords, $t(15) = 4.5$, $p < .001$, $\eta^2 = .57$. This demonstrates a significant improvement in infants' treatment of nonwords that are mismatched in pitch from 7.5 months, when recognition scores for these familiarization items did not depart significantly from zero. A pairwise comparison of recognition scores for mismatched nonwords between Experiment 1 and this experiment revealed significantly different recognition scores for 7.5-month-olds and 10.5-month-olds, $t(15) = 2.12$, $p = .05$, $\eta^2 = .23$.

The important distinction drawn by Experiment 2 is that the older infants seem to have developed the capacity to recognize unfamiliar nonwords when mismatched in pitch, indicating a marked improvement in their capacities for spoken word recognition when unaided by surface similarity, familiarity, or both. A second distinction is that there were no significant effects of item in the familiar word condition, indicating that infants were equally capable of recognizing *Mommy* and *Daddy* by this stage.

These findings evince a qualitative improvement in word recognition by 10.5 months in that infants recognized previously unfamiliar nonwords, even though they had undergone a surface transformation between familiarization and recognition. This suggests that although word familiarity might potentiate more abstract word recognition in infants at 7.5 months, by 10.5 months, infants seem to have acquired some knowledge of the lexical irrelevance of pitch and are able to apply to this knowledge to familiar and entirely unfamiliar nonwords alike.

GENERAL DISCUSSION

Word recognition indisputably involves the capacity to recognize words amidst whatever surface changes might alter their physical form. Findings from this study demonstrate that at 7.5 months, word familiarity exerts strong effects not necessarily on segmentation, but rather on this capacity to cope with surface variation in segmentation tasks. Highly familiar words are segmented more robustly (i.e., in spite of changes in surface form) than entirely unfamiliar words, which are only segmented when they match in surface form. By contrast, at 10.5 months, such selective effects of word familiarity seem to have diminished, revealing an impressive capacity to segment highly familiar as well as entirely unfamiliar words from fluent speech. This suggests that by this age, infants have discerned which dimensions of sound are nonphonemic, and are able to disregard those in word recognition tasks.

Although it is clear that word familiarity confers certain advantages in resolving the variability problem, it remains unclear what exactly about familiar items is facilitative. There are several potential reasons why words such as *Mommy* and *Daddy* might be privileged in segmentation tasks. First, it is possible that they simply recruit attention more effectively in familiarization and recognition and therefore lead to higher listening times throughout. (This seems unlikely as there was no main effect of familiarity (i.e., *Mommy*, *Daddy* vs. *Luka*, *Ghana*) in looking times toward familiarization or recognition trials in either 7.5- or 10.5-month-old infants in this pair of studies). A second possibility is that *Mommy* and *Daddy* are simply highly frequent items in the child's input and one possible consequence of differential exposure is improved recognition of these items. In this case, we would expect observed effects of word familiarity to amount to effects of word frequency, whereby other highly frequent words would be equivalently privileged in segmentation. A third possibility is that words like *Mommy* and *Daddy* are more than simply statistically frequent; rather, they might carry a special emotional valence that draws infants' attention to a greater extent than other highly frequent items. Therefore, it is possible that these words receive premature attention in emerging word knowledge as a function of their social value to an infant. Finally, it is possible that infants know the meanings of the words *Mommy* and

Daddy at this age, and that having a conceptual representation of a word contributes to more effective resolution of the variability problem. It stands to reason that having an underlying meaning for different exemplars of a word would facilitate the task of equating these exemplars despite their surface differences. Therefore, when we employ the term *familiarity*, it could realistically comprise one or more of the following factors: attention-getting properties, highly frequent input statistically, social-emotional significance, or underlying semantic representation.

An important issue in dealing with variability is how to weigh the importance of the discriminable acoustic cues present in the input. The findings of these experiments suggest that two cues are potentially relevant: word frequency and word-form similarity. Certainly, the presence of either one of these factors seems to ease the burden of early word segmentation, although there seems to be no particular advantage attached to either factor in isolation. A comparison of recognition scores across items suggests that the simultaneous presence of both factors (familiarity and a surface match, as in matched *Mommy* or *Daddy*) does not result in significantly higher recognition scores than the individual presence of either factor. Moreover, the presence of familiarity did not result in significantly different recognition scores than the presence of a surface match across familiarization and recognition. Therefore, although the absence of both factors is seriously detrimental to word recognition at 7.5 months, each factor in isolation seems to benefit word recognition as much as both factors in combination. Collectively, these findings suggest that these factors might indeed be comparable in their effects on early word recognition.

Although matched surface form and familiarity might each contribute significantly to the success of early word segmentation, they are likely not the only routes by which word segmentation can be strengthened. Rather, there are likely to be several potential catalysts of mature word recognition. For example, there is recent experimental evidence to suggest that the presence of high suprasegmental variation, such as extensive variation in talker gender and vocal affect, can actually improve segmentation (Houston, 2000; Singh, in press). These findings demonstrate that when 7.5-month-old infants are familiarized with words spoken by multiple talkers or in multiple affective styles, word segmentation improves as a function of increased variability. This is presumably because high surface variation highlights the phonological invariants that define the lexical identity of a word. It can be hypothesized that pitch variation during familiarization might benefit word segmentation for similar reasons. It is possible, for example, that increased suprasegmental variation in the familiarization of nonwords can compensate for infants' lack of familiarity with these items and that this experience, in and of itself, could improve recognition of nonwords.

An important question to arise from this study is the issue of what mechanisms drive the maturation of spoken word recognition from 7.5 to 10.5 months. In particular, what accounts for the improved recognition of nonwords? It is not reasonable to suppose that words such as *Luka* and *Ghana* have been associated with a conceptual representation of any kind. Therefore, the drivers of this maturation are not semantic. However, it remains to be determined whether infants have simply learned to disregard pitch or whether they have developed the ability to form abstractions of words that are stored in the early phonological lexicon. These possibilities are not mutually exclusive and certainly learning to disregard pitch and other forms of nonphonemic detail are a necessary conduit to forming abstractions of words. These possibilities are not separated by this study and are not easy to separate in any empirical investigation of prelexical information when top-down influences, commonly associated with abstract representation, are difficult to ascertain. One means by which to determine whether infants have disregarded pitch versus formed abstractions would be to investigate treatment of pitch contours in learners of tonal languages. If infants born into bilingual tonal and nontonal languages (e.g., Mandarin Chinese and English) can dissociate pitch that imparts tonal variation from that which imparts intonational variation by 10.5 months when faced with nonwords, this would point compellingly to a capacity for abstraction that transcends a simple disregard for pitch. Rather, this would suggest a selective attention to pitch based on its functionality within a language.

The resolution of the variability problem has remained an elusive challenge in the study of child language development, adult language processing, and machine learning. Hence, discovery of factors that contribute to the resolution of variability are of potential relevance to each of these domains. Given the inescapable ubiquity of surface variation in natural speech and its attested disruptions on processing, knowledge of these factors has potentially important consequences for the elaboration of psycholinguistic models of language processing.

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APPENDIX

Familiarization Items

Luka

Ghana

Mommy

Daddy

Recognition Passages

Luka spends time playing with friends.

Luka enjoys doing her work.

I like Luka to bake cookies.

I love it when Luka eats her dinner.

I like to think about Luka.

The best person in the world is Luka.

Ghana has a big red bottle.

Ghana likes to walk her dog.

I find Ghana fun to be with.

I like Ghana and her sister.

I think the shoe belongs to Ghana.

I give all my best wishes to Ghana.

Daddy likes to wash his car.

Daddy wants to sit outside and read.

I like Daddy to sit inside.

I love it when Daddy works at home.

There’s no one I love more than Daddy.

I want to be just like Daddy.

Mommy went to the store today.

Mommy likes to play with blocks.

I like Mommy to brush my hair.

I want Mommy to drink her tea.

I want to give my cup to Mommy.

I like to spend time with Mommy.

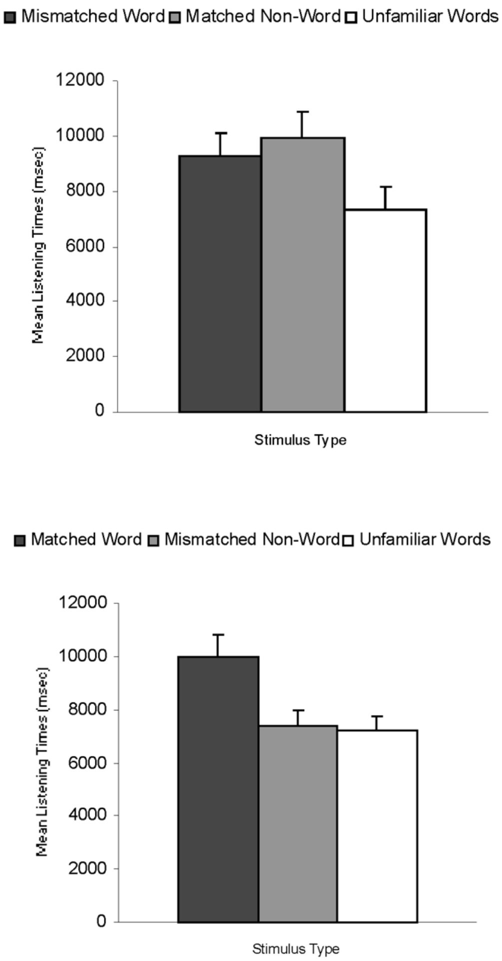

FIGURE 1.

(a) 7.5-month-old listening times (with standard error) to sentences containing matched nonwords, mismatched words, and unfamiliar sentences; (b) 7.5-month-old listening times (with standard error) to sentences containing matched words, mismatched nonwords, and unfamiliar sentences.

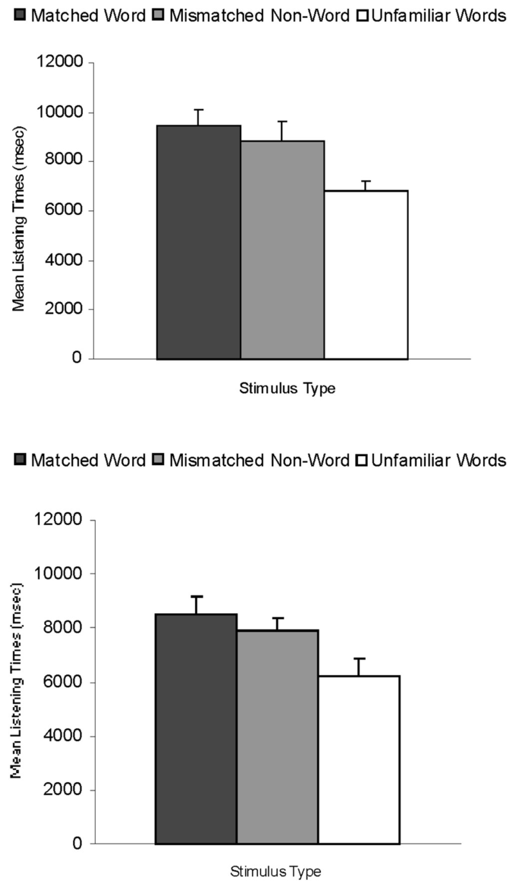

FIGURE 2.

(a) 10.5-month-old listening times (with standard error) to sentences containing matched nonwords, mismatched words, and unfamiliar sentences; (b) 10.5-month-old listening times (with standard error) to sentences containing matched words, mismatched nonwords, and unfamiliar sentences.

TABLE 1

Acoustic Measurements of High and Low Pitch Words

	Minimum F0 in Hz		Maximum F0 in Hz		Average F0 in Hz		Duration in msec	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
High-pitch words	315.2	143.79	469.81	174.21	386.38	160.22	552.26	23.53
Low-pitch words	205.78	89.5	314.5	118.16	256.5	105.69	555.54	23.90

TABLE 2

Experimental Design and Stimulus Manipulations

Match and Familiarity Manipulation	Familiarization Stimuli		Recognition Stimuli
Condition 1a: matched nonword and mismatched word High-recognition passages (*n* = 8 at each age group)	*Luka* or *Ghana* High pitch	*Mommy* or *Daddy* Low pitch	*Luka*, *Ghana*, *Mommy*, *Daddy* (in carrier sentences) High pitch
Condition 1b: Matched nonword and mismatched word Low-recognition passages (*n* = 8 at each age group)	*Luka* or *Ghana* Low pitch	*Mommy* or *Daddy* High pitch	*Luka*, *Ghana*, *Mommy*, *Daddy* (in carrier sentences) Low pitch
Condition 2a: Matched word and mismatched nonword Low-recognition passages (*n* = 8 at each age group)	*Luka* or *Ghana* High pitch	*Mommy* or *Daddy* Low pitch	*Luka*, *Ghana*, *Mommy*, *Daddy* (in carrier sentences) Low pitch
Condition 2b: Matched word and mismatched nonword High-recognition passages (*n* = 8 at each age group)	*Luka* or *Ghana* Low pitch	*Mommy* or *Daddy* High pitch	*Luka*, *Ghana*, *Mommy*, *Daddy* (in carrier sentences) High pitch