Newborn infants' sensitivity to perceptual cues to lexical and grammatical words

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Abstract

In our study newborn infants were presented with lists of lexical and grammatical words prepared from natural maternal speech. The results show that newborns are able to categorically discriminate these sets of words based on a constellation of perceptual cues that distinguish them. This general ability to detect and categorically discriminate sets of words on the basis of multiple acoustic and phonological cues may provide a perceptual base that can help older infants bootstrap into the acquisition of grammatical categories and syntactic structure.

1. Introduction

It has been shown in many previous studies that infants have remarkable perceptual sensitivities to fine acoustic/phonetic details of speech (Jusczyk, 1997). Moreover, by 6–8 months of age, infants show abilities to use probabilistic information (Saffran, Aslin & Newport, 1996) and patterns of co-occurrence (Marcus, Vijayan, Bandi Rao & Vishton, 1999; Goodsitt, Morgan & Kuhl, 1993) to detect structure and rules. These abilities may help explain, in part, why older infants are so good at perceptually categorizing stimuli that vary on multiple dimensions. Indeed, even newborn infants can discriminate syllables on the basis of phonetic category (Eimas, Siqueland, Jusczyk & Vigorito, 1971), syllable form (Bertoncini & Mehler, 1981), intonation (Nazzi, Floccia & Bertoncini, 1998b), and number of syllables (Bijeljac-Babic, Bertoncic & Mehler, 1993). Moreover, newborns show categorical discrimination of distinct languages (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini & Amiel-Tison, 1988; Nazzi, Bertoncini, & Mehler, 1998a), raising the possibility that they may be sensitive to multiply occurring acoustic phonetic cues. We ask here if infants presented with lists of lexical and grammatical words can make *categorical* generalizations across such lists. This, in particular, may yield clues as to whether infants can detect constellations of probabilistically occurring perceptual cues in input speech that distinguish these two fundamental syntactic categories (Shi, Morgan & Allopenna, 1998). Furthermore, we ask whether this sensitivity is present in the neonate.

How children gain knowledge of syntactic categories of human languages is one of the most perplexing and important questions in the field of language acquisition. Categories such as nouns, verbs, prepositions and auxiliaries are the essential building blocks of adult grammar. They constitute the elements that are combined and ordered to produce and understand the infinite numbers of sentences possible in any language. Development of the ability to assign words to their appropriate syntactic categories is therefore crucial to language acquisition. This task, however, is by no means trivial. Because syntactic categories are, at least in part, defined in terms of their positions relative to one another in sentences, learners cannot rely solely on statistical patterns of co-occurrence to derive initial categories. Thus, infants need some other independent means to help them break into the system. One potential source of information about syntactic categories, explored in several recent studies (e.g. Shi et al., 1998; Morgan, Shi, & Allopenna, 1996; Shi, 1995; Kelly, 1992) lies in perceptual cues available in input speech.

The distinction between lexical and grammatical words is particularly interesting because although languages differ significantly, and somewhat arbitrarily, in precisely which syntactic categories are included, the distinction between lexical and grammatical words is thought to be universal (Abney, 1987). The lexical category includes meaning-related open-class 'content' words such as nouns, verbs, adjectives, and adverbs. The grammatical category includes those closed-class 'function' words that are primarily structural, such as articles, prepositions, and auxiliaries. A series of recent studies have revealed that in a variety of languages speech to infants and young children contains sets of acoustical and phonological cues sufficient in principle to distinguish lexical and grammatical words (Shi et al., 1998; Morgan et al., 1996; Shi, 1995). In-depth acoustic analyses performed on words excised from spontaneous infant-directed utterances in three typologically distinct languages (English, Mandarin, and Turkish) showed that in all three languages, grammatical words tended to be acoustically and/or phonologically minimized in comparison to lexical words (for example, short vowel duration, weak amplitude and simplified syllable structure). The results further showed that no individual cue alone served as a reliable basis for predicting membership in the two classes. It was only with the full constellations of acoustic and phonological cues that these two categories were distinguishable. With the full set of cues, simulations with unsupervised, self-organizing neural networks assigned words to the appropriate categories with 86% accuracy (see Shi et al., 1998 for a detailed discussion of individual versus multiple cues). These results show that there is sufficient information in input speech to distinguish these two fundamental grammatical categories, but that this information is neither obvious nor trivial to access.

The question of interest for our study was whether newborn infants are able to use such probabilistic combinations of acoustic and phonological information to perceptually separate English word tokens into distinct categories. At a later stage, such an ability could potentially help 'bootstrap' infants into acquisition of grammar by allowing them to detect and represent classes of words on the basis of perceptible surface cues. To examine whether such an ability, if present, is universal, newborns whose mothers spoke only English were compared with newborns whose mothers primarily spoke other languages.

2. Experiment 1

Method

In this experiment, 77 1-to 3-day-old healthy newborns were tested in an infant-controlled habituation paradigm using a high amplitude sucking procedure (Siqueland and DeLucia, 1969). Thirty-two infants (15 male, 17 female) completed the study. Of these, 17 infants had mothers who spoke only English, whereas 15 infants had mothers who primarily spoke languages other than English[1]. The remaining 45 did not complete the experiment for a variety of reasons[2]. In this high amplitude sucking procedure, infants are presented with a stimulus every time they deliver a strong (high amplitude, HA) suck. Initially, the rate of HA sucks tends to be high to new stimuli. As the infant becomes familiar with the stimuli, the rate of HA sucking declines. Once the sucking rate declines to a preset criterion level, infants are presented with a new set of stimuli. Because infants show a preference for novelty, if the new stimuli are discriminable from those presented in the habituation phase, there should be a recovery in the rate of HA sucking.

Auditory stimuli in this experiment were repetitions of words analyzed in previous studies (Morgan et al., 1996; Shi, 1995), which had been randomly selected from an audio recording of the natural speech of an English-speaking mother to her one-year-old child. For this study, 56 tokens (28 lexical and 28 grammatical) were randomly selected. Note that grammatical types tend to occur with higher frequencies than do lexical types, so that the type/token ratio of lexical words is considerably higher than that of grammatical words (cf. Kucera and Francis, 1967). This was

[1] Of these mothers, five spoke Cantonese, Mandarin, or both, four spoke Punjabi, three spoke Tagalog, two spoke Spanish, and one spoke French and Swiss German bilingually.

[2] Reasons for discarding infants included: failure to suck after habituation (10), spitting out the nipple (8), failure to habituate (7), failure to provide sufficient numbers of high-amplitude sucks (6), sleeping (6), crying or fussiness (5), experimenter error (3).

characteristic of our corpus as well. To ensure that our stimuli reflected naturally occurring properties of input speech, we decided that our stimuli should manifest, at least in part, this natural difference. Therefore, for the 28 randomly selected lexical tokens, there were 21 types, six of which were represented by more than one token, whereas for the 28 randomly selected grammatical tokens, there were eight types, six of which were represented by multiple tokens. Note that the multiple tokens for both the lexical and grammatical types occurred in different sentential contexts and were acoustically distinct from each other. In dividing the types from each category into two lists, we ensured that the number of types that occurred once and those that occurred more than once were placed in each list in a balanced way, so that one list would not be a subset of the other.

Because the original tokens were produced in continuous speech, there was considerable coarticulation. Thus, excised tokens would sound artificial. To remedy this, the tokens were reproduced by another female speaker who mimicked the original utterances as closely as possible, but introduced a brief silence before and after each target word. This method of reproducing the utterances was employed to ensure that the acoustic characteristics of the tokens (especially grammatical words) in sentential contexts were preserved, which would have been eliminated if they were reproduced in isolation. The 56 tokens were each mimicked three times. These mimicked token-repetitions were used as stimuli. The final stimuli comprised two lists of grammatical items and two lists of lexical items, as shown in Table 1. The two grammatical lists each consisted of 42 token-repetitions (14 tokens $\times$ 3 repetitions each). The two lexical lists each consisted of 38 token-repetitions (a small number of lexical token-repetitions failed to be mimicked with preceding and following silent intervals and were therefore removed from the final stimulus lists).

A series of acoustic analyses, parallel to those in the previous work (Morgan et al., 1996; Shi, 1995) were conducted to ensure that the mimicked repetitions preserved the essential characteristics of the original tokens. There were no differences between the originals and the repetitions for either lexical or grammatical items in vowel duration (lexical: $t = 0.372$, $P = 0.71$; grammatical: $t = 0.235$, $P = 0.815$), or pitch change (lexical: $t = 1.285$, $P = 0.2$; grammatical: $t = 1.396$; $P = 0.17$). As was the case for the original tokens, the vowels in the lexical token-repetitions were more dispersed from a neutral vowel (the center of the speaker's vowel space) than were those of the grammatical token-repetitions ($t = 3.686$, $P = 0.0003$). Overall, the relative patterns of acoustic differences between the two categories of mimicked items corresponded to those of the original[3]. Importantly, although the categories of items displayed mean differences on several measures, on every such measure there was substantial overlap in the distributions of values. Thus, as was the case for the original tokens, no single measure would provide a sufficient basis for accurate classification of individual token-repetitions.

[3] Mimicked lexical and grammatical token-repetitions differed in amplitude ($t = 3.108$, $P = 0.0022$), as did the original tokens. However, because previous research (Sinnott & Aslin, 1985) has suggested that infants may dishabituate asymmetrically to louder versus softer stimulus sets, the token-repetitions were adjusted so that the stimulus sets presented to infants did not differ in amplitude.

Table 1
Stimuli[a]

Llist1 (38 items)
Taste*3, showing*2, play*3, chew*3, found*3, again*2, going*2, mommy$_A$*2, mommy$_B$*3, hide$_A$*3, mommy's$_A$*3, cookie$_A$*3, chair$_A$*3, find$_A$*3
Llist2 (38 items)
Toys*3, read*3, new*3, hear*2, bounced*3, ernie*3, great*3, ball*1, hide*3, mommy's$_B$*3, cookie$_B$*2, chair$_B$*3, find$_B$B*3, mommy's$_C$*3
Glist1 (42 items)
In$_A$*3, in $_B$*3, a$_A$*3, a$_B$*3, you$_A$*3, you$_B$*3, you$_C$*3, you$_D$*3, you$_E$*3, its*3, the$_A$*3, the$_B$*3, your$_A$*3, your$_B$*3
Glist2 (42 items)
In$_C$*3, in$_D$*3, a$_C$*3, a$_D$*3, a$_E$*3, you$_F$*3, you$_G$*3, you$_H$*3, you$_I$*3, you$_J$*3, you$_K$*3, you$_L$*3, we*3, that's*3

[a] The items in each list were presented in random orders that differed across infants. Subscripted letters A–E following some of the words indicate that these words occurred in different sentential contexts.

However, as was again the case for the original tokens, the complete constellation of measures did provide a sufficient basis for accurate classification: a Kohonen-style unsupervised, self-organizing neural network simulation run on the set of measures showed that, with only a single exception, no token-repetitions were misclassified by the network.

Infants were tested individually in a soundproof room about 2 h after feeding. They were put in a reclining seat and then were given a blind nipple to suck. The nipple was connected through a plastic tube to a Gould P23 pressure transducer, which then connected to an IBM-PC compatible computer. Air pressure changes in the tube caused by infant's sucks were registered by the computer. The software was programmed to present pre-recorded auditory stimuli to a speaker through an amplifier contingent upon HA sucks. During the first minute, the base-line amplitude of sucking for the infant was established. Following this, any suck that was in the top 80% of sucking amplitude for that infant triggered the presentation of a word. The number of HA sucks per minute was coded automatically by the program, and was used on line to determine habituation. To reach habituation criterion, the average number of sucks per minute for two consecutive minutes had to be 75% or less than the number of sucks of the immediately preceding minute. Upon habituation, the program automatically shifted to the test phase.

After being habituated to one list of tokens (of either the grammatical or lexical category), infants were tested on novel lists of tokens. Infants in the experimental group were tested on a list of tokens from the opposite category. Infants in the control group were tested on another list of words from the habituation category. This design allowed us to see whether newborn infants would treat the switch to a new category of words as more distinct than a switch to a new list from the same category.

Results and discussion

A preliminary analysis was conducted to ensure that infants in all habituation conditions had equivalent exposure to the stimuli. There were no significant differences during the habituation phase in total number of HA sucks towards the lexical versus the grammatical words: infants in both conditions had equivalent exposure during the habituation phase. This is important as it indicates that infants found lists of both types to be equally interesting.

The average number of HA sucks per minute during the final 2 min of the habituation phase was compared to the average number during the first 2 min in the test phase. Paired t-tests were conducted for each group. There was significant recovery in the experimental group, $t(15) = 5.514$; $P < 0.0001$, but not in the control group $t(15) = 1.586$; $P = 0.1336$ (see Fig. 1). To compare recovery across groups, the difference between HA sucks in the first test trials minus those in the last habituation trials was computed to form a *recovery score* for each infant. We expected recovery scores to be greater in the experimental group than in the control group; this expectation was confirmed by an unpaired t-test performed on recovery scores, $t(30) = 3.225$; $P < 0.002$ (1-tailed). A follow-up analysis showed that both directions of change within the experimental group showed significant recovery from habituation: grammatical to lexical, $t(7) = 3.612$, $P = 0.0086$; lexical to grammatical, $t(7) = 6.057$, $P = 0.0005$.

To examine whether newborns' ability to distinguish among these sets of English items may have been affected by the character of prenatal language exposure, two additional sets of analyses were conducted. For the 17 infants whose mothers spoke English only, paired t-tests revealed significant recovery in the experimental group, $t(8) = 5.426$; $P = 0.0006$, but not in the control group, $t(7) = 0.937$; $P = 0.38$. An

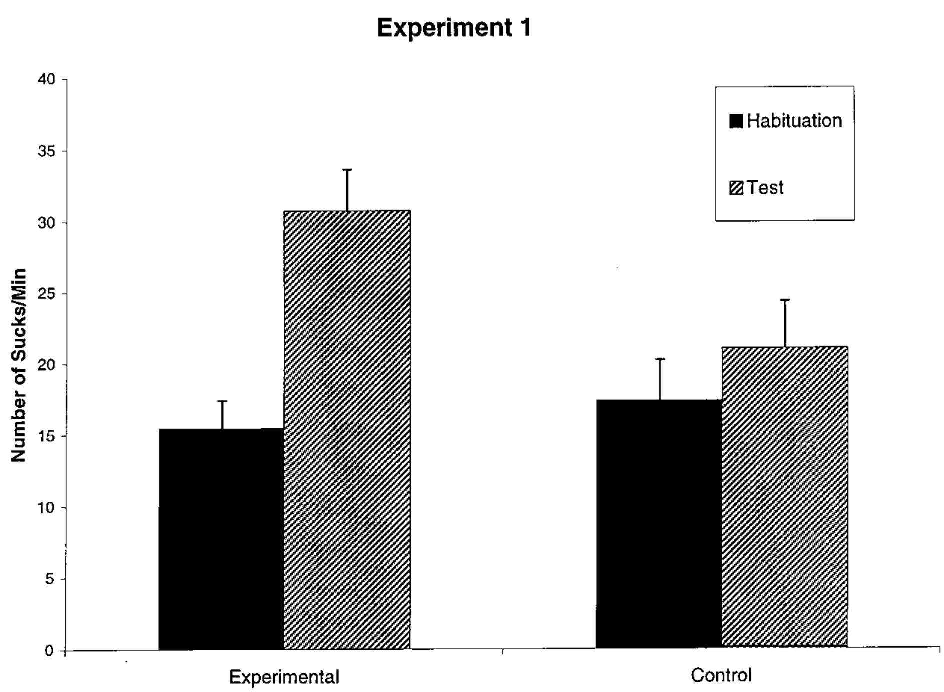

Fig. 1. Experiment 1. Means and SEs of HA sucks by newborns for the last 2 min of habituation phase and the first 2 min of test phase for the control and experimental conditions.

unpaired t-test comparing recovery scores confirmed our a priori prediction of greater recovery in the experimental than in the control group; $t(15) = 2.404$; $P < 0.02$ (1-tailed). The 15 infants whose mothers spoke a language other than English also displayed significant recovery in the experimental group, $t(6) = 2.859$; $P = 0.0288$, but not in the control group, $t(7) = 1.319$; $P = 0.229$. Again, an unpaired t-test comparing recovery scores confirmed that there was greater recovery in the experimental than in the control group; $t(13) = 2.044$; $P < 0.04$ (1-tailed).

These results indicate that the difference between lists of lexical and grammatical words is more perceptually salient to newborn infants than is the difference between two different lists of words from the same syntactic category. Moreover, neonates' ability to distinguish these two categories of English words is robust across different pre-natal language experiences. However, an alternative possibility may account for these results. To best reflect the characteristic of natural parental speech input, our stimuli were unbalanced in terms of the number of types and number of syllables for lexical versus grammatical words. As mentioned earlier, there were more word types for lexical word lists (21) than for grammatical word lists (8), and there was some overlap of types across the two word lists of each category. In addition, lexical lists contained both monosyllabic and bisyllabic words whereas grammatical lists contained only monosyllabic words; previous work has shown that infant can discriminate lists of words containing different numbers of syllables (Bijeljac-Babic, Bertoncini & Mehler 1993). To determine whether these factors accounted for the results from Experiment 1, we conducted an additional experiment using stimuli that were balanced in the number of types and syllables across all lexical and grammatical word lists, and we ensured that each list contained completely novel word types.

3. Experiment 2

Method

In Experiment 2, 37 1- to 3-day-old newborns were tested in the same infant-controlled high amplitude sucking habituation paradigm. Sixteen infants (12 male, 4 female) completed the experiment. The remaining 21 did not complete the experiment for a variety of reasons[4]. Auditory stimuli in this experiment were a randomly selected subset of the stimuli used in Experiment 1. Lexical and grammatical words were balanced in the number of types and syllables. There were eight types for lexical words, each with three instances. There were also eight types for grammatical words, each with three instances. Final stimuli comprised two lists of grammatical words and two lists of lexical words, as shown in Table 2. The two grammatical

[4] Reasons for discarding infants included: failure to suck after habituation (3), spitting out the nipple (7), failure to habituate (3), failure to provide sufficient numbers of high-amplitude sucks (3), crying or fussiness (2), two or more consecutive minutes of 0 HA sucks (2), and grandmother interfering in the experiment (1).

Table 2
Stimuli[a]

Llist1 (12 items)	
Toys*3, chew*3, $chair_A$*2, $chair_B$*1 $find_A$*2, $find_c$*1	
Llist2 (12 items)	
Great*3, play*3, bounced*3, $hide_A$*2, $hide_B$*1	
Glist1 (12 items)	
Its*3, the*3, in_A*2, in_B*1, $your_A$*2, $your_B$*1	
Glist2 (12 items)	
We*3, that's*3, a*3, you_A*2, you_B*1	

[a] The items in each list were presented in random orders that differed across infants. Subscripted letters A–B following some of the words indicate that these words occurred in different sentential contexts.

lists each consisted of 12 instances (four types × three each), as did the lexical lists. These four stimulus lists were completely non-overlapping in word types.

Newborn infants were tested in the same HAS procedure as used in Experiment 1. As before, after being habituated to one list of tokens (of either the grammatical or lexical category), infants were tested on novel lists of tokens. Infants in the experimental group were tested on a list of tokens from the opposite category. This time we ensured that for the control group, we used completely novel lists of words from the habituation category.

By entirely eliminating any overlapping word type, we were able to provide the strongest possible test of categorical discrimination. If our conclusions from Experiment 1 were correct, infants in the experimental group in Experiment 2 should still be able to discriminate a change to a new list of words even when two naturally occurring cues, type/token ratio and number of syllables were controlled. The use of a small number of items coupled with completely novel word types in the comparison lists in the control group presented the possibility that infants would show recovery in this condition based simply on their ability to recognize new items. Nevertheless, we expected that infants in the control group would show less recovery than infants in the experimental group.

Results

A preliminary analysis was conducted to ensure that infants in all habituation conditions had equivalent exposure to the stimuli. There were no significant differences during the habituation phase in total number of HA sucks toward the lexical versus the grammatical words; infants in both conditions had equivalent exposure during the habituation phase, as in Experiment 1.

The average number of HA sucks per minute during the final 2 min of the habituation phase were compared to the average number of HA sucks during the first 2 min in the test phase. Data are shown in Fig. 2. As in Experiment 1, paired *t*-tests were conducted for each group. The results for the experimental group were highly significant $t(7) = 4.146$; $P < 0.005$, but did not quite reach the conventional level of significance for the control group, $t(7) = 2.151$; $P = 0.0685$. As in Experi-

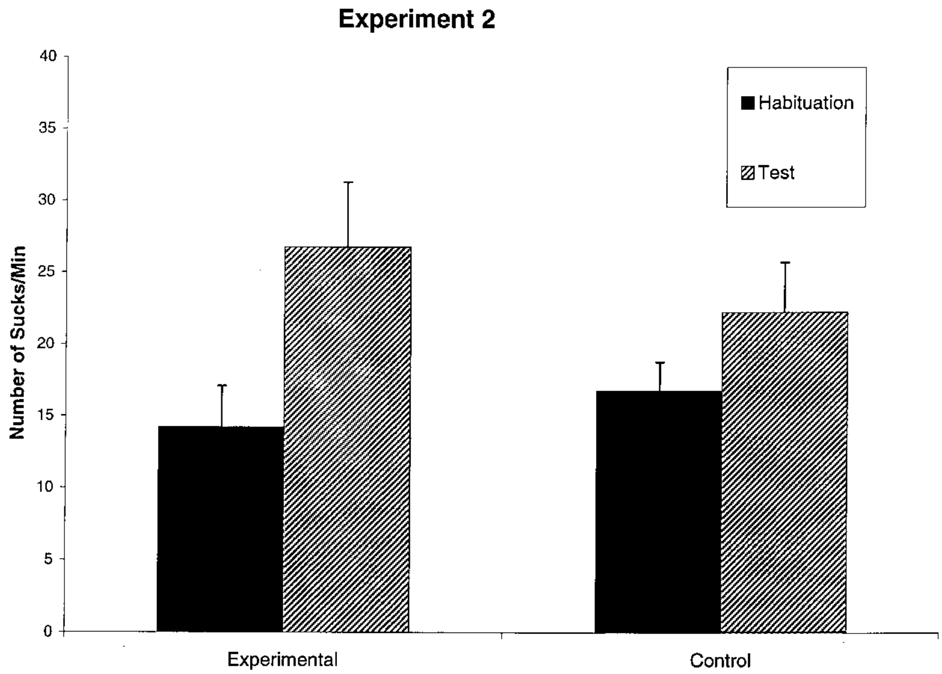

Fig. 2. Experiment 2. Means and SEs of HA sucks by newborns for the last 2 min of habituation phase and the first 2 min of test phase for the control and experimental conditions.

ment 1, a one-tailed unpaired t-test was performed to test the prediction that recovery scores would be greater in the experimental than in the control group. This was confirmed, $t(14) = 1.781$; $P < 0.05$ (one-tailed). Thus, despite the fact that the stimuli used in this experiment decreased discriminability for the experimental subjects (because we had eliminated two of the naturally occurring distinctive cues for lexical versus grammatical categories: type/token ratio and number of syllables), and increased discriminability for the control groups (because there were entirely new items on the test lists), this experiment replicated the pattern of results reported in Experiment 1.

4. General discussion

The results of Experiments 1 and 2 both indicate that the difference between lexical and grammatical words is more perceptually salient to newborn infants than is the difference between two lists of words from within either category. We know from previous work that infants as young as 8 months are able to use probabilistic cues in input speech to learn acceptable word sized units (Saffran et al., 1996) and that infants as young as 7 months can detect patterns of co-occurrence (Gomez & Gerken, 1999; Marcus et al., 1999; Goodsitt et al., 1993). This work, however, shows that newborns are sensitive to probabilistic constellations of perceptual cues and can use that ability to categorically discriminate lists of words. These results invite consideration of the possibility that the particular constellations of acoustic and phonological cues that languages use to signal linguistically important distinctions – such as the fundamental distinction between lexical and grammatical categories – may be tailored to fit initial perceptual processing abilities, so that a biologically given general perceptual mechanism can be exploited in the later acquisition of syntactic structure.

Several interpretive caveats are in order. First, the fact that infants can categorically discriminate lists of words drawn from two different classes does not constitute evidence for precocious knowledge of grammatical categories. Our findings show merely an early ability to use surface perceptual cues to sort acoustic forms on the basis of similarity, albeit similarity based on correlated cues rather than individual cues. Moreover, we do not claim from these results that infants are able to segment words from natural speech and then divide the words into two classes. But, like many other experiments that present words or syllables in isolation, we can claim that when individual words are presented, infants can categorically discriminate them.

As indicated above, the early ability to categorically discriminate sets of lexical and grammatical words does not imply that infants have inferred the syntactic properties or appreciate the semantic implications accompanying these categories, let alone that they have formed these categories themselves. But this ability does reflect a set of general perceptual processing capacities that may later – with the advent of word segmentation in the second 6 months (cf. Jusczyk & Aslin, 1995) – help bootstrap the infant into the eventual acquisition of syntactic categories. The initial sorting of words into two elementary categories on the basis of the surface acoustic and phonological cues may assist infants in subsequently solving fundamental problems of grammar, including the acquisition of refined sets of language-specific syntactic categories and apprehension of sentence phrase structure (Morgan et al., 1996). This remarkable early ability to categorically discriminate lexical versus grammatical words based on constellations of cues may thus be a critical first step in breaking into the syntactic system of human languages.

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References

Abney, S.P., 1987. The English noun phrase and its sentential aspect. Ph.D. dissertation, MIT.

Bertoncini, J., & Mehler, J. (1981). Syllables as units in infant speech perception. *Infant Behavior and Development*, *4*, 247–260.

Bijeljac-Babic, R., Bertoncini, J., & Mehler, J. (1993). How do four day old infants categorize multi-syllabic utterances. *Developmental Psychology*, *29*, 711–721.

Eimas, P., Siqueland, E., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science*, *171*, 303–306.

Gomez, R. L., & Gerken, L. (1999). Artificial grammar learning by one-year-olds leads to specific and abstract knowledge. *Cognition*.

Goodsitt, J., Morgan, J. L., & Kuhl, P. K. (1993). Perceptual strategies in prelingual speech segmentation. *Journal of Child Language*, *20*, 229–252.

Jusczyk, P. W., & Aslin, R. N. (1995). Recognition of familiar patterns in fluent speech by 7 1/2 month old infants. *Cognitive Psychology*, *29*, 1–23.

Jusczyk, P. W. (1997). *The discovery of spoken language*, Cambridge, MA: MIT Press.

Kelly, M. (1992). Using sound to solve syntactic problems: The role of phonology in grammatical category assignments. *Psychological Review*, *99*, 349–363.

Kucera, H., & Francis, N. (1967). *A computational analysis of present-day English*, Providence, RI: Brown University Press.

Marcus, G. F., Vijayan, S., Bandi Rao, S., & Vishton, P. M. (1999). Rule learning by seven-month-old infants. *Science*, *283*, 77–80.

Mehler, J., Jusczyk, P. W., Lambertz, G., Halsted, N., Bertoncini, J., & Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition*, *29*, 143–178.

Morgan, J. L., Shi, R., & Allopenna, P. (1996). Perceptual bases of rudimentary grammatical categories. In J. Morgan & K. Demuth, *Signal to Syntax*, (pp. 263–283). Hillsdale, NJ: Lawrence Erlbaum Associates.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998a). Language discrimination by newborns: towards an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1–11.

Nazzi, T., Floccia, C., & Bertoncini, J. (1998b). Discrimination of pitch contours by neonates. *Infant Behavior and Development* , *21* (4), 779–784.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8monthold infants. *Science*, *274*, 1926–1928.

Shi, R., Morgan, J. L., & Allopenna, P. (1998). Phonological and acoustic bases for early grammatical category assignment: A cross-linguistic perspective. *Journal of Child Language* , *25*, 169–201.

Shi, R., 1995. Perceptual correlates of content words and function words in early language input. Ph.D. dissertation, Brown University.

Sinnott, J. M., & Aslin, R. N. (1985). *Frequency and intensity discrimination in human infants and adults. Journal of Acoustical Society of America*, *78*, 1986–1992.

Siqueland, E. R., & DeLucia, C. A. (1969). Visual reinforcement of non-nutritive sucking in human infants. *Science*, *165*, 1144–1146.