A RATIONALIST APPROACH TO THE STUDY OF DEVELOPMENT.

Humans are helpless at birth but in a few years they learn a great many things, gain increasing autonomy, and acquire motor and perceptual skills as well as language and numerical abilities. How does such a change come about? Observers often marvel at the speed and predictability of growth. For instance, the tri-dimensional organization of space emerges sometime between 16 and 18 weeks after birth (see Held, Birch, & Gwiazda, 1980). Motor learning unfolds predictably, bipedal gait being attained at the end of the first year of life (see Adolph, 1995). Likewise, language unfolds after only a few years of contact with the environment (see Brown, 1973). Major deviations from this schedule usually signal neurological impairment. Psychologists, borrowing terms from biology, tend to refer to these changes as development. It was biologists who first began to describe the predictable changes that take place as the fertilized egg progressively grows into the fully-fledged organism. In this sense, the term development is theoretically neutral : it is simply a word that describes the changes that take place during growth.

A survey of the first half of the twentieth century shows that behavioral scientists slighted the study of development until Piaget's influence began to be felt, roughly, at the time when Cognitive Psychology was beginning to gain a wider audience. Up until that time, most psychologists believed that living creatures learn by extracting regularities from their environment. Association was the mechanism offered to explain learning. It is not readily obvious, however, how association can explain the origin of species-specific behavioral dispositions (see Tinbergen, 1951; and also Gallistel, 1990). Associationists attributed species-specific behaviors to unequal learning opportunities. Humans, the argument would go, are in closer contact with language than chimps; bats have more exposure to ultra-sonic stimulation than humans who, in contrast, have greater access to visual depth cues than bats and so forth. Nowadays, we scoff at such beliefs and simply regard them as ludicrous. However, they did pervade the behaviorist credo for decades, which explains why it was so easy to neglect the study of development. Of course, if one believed that abilities were constructed exclusively by means of associative learning, then it made sense to study the learning mechanism by itself in tightly-controlled experimental situations, without taking into account the many factors that play a role during live development.

The revolution that changed the contemporary conception of the mind, was instigated by Turing and Chomsky. Turing provided us with the demonstration that mental processes can be compared to computation by machines. Chomsky (1957) demonstrated that the knowledge of language consists in a grammatical system, or a «discrete infinity», that elucidates how natural languages can construct an infinite number of sentences and meanings with a finite number of lexical items and a handful of rules to combine them. The question that proponents of such a conception must address is how grammatical systems are learned. Chomsky (1965) did not shy away from such a task, rather, he turned it into a central aspect of his theory. Indeed, he proposed that humans learn language because they, and only they, are endowed with Universal

Grammar (UG). UG highlights the underlying structural similarities found in all natural languages despite the seeming differences that descriptive linguists have identified. Chomsky's aim was to elaborate a theory with strong descriptive and explanatory adequacy. That is, UG is interesting only as a theory on the properties that make it possible for the human mind to acquire language under favorable conditions. Chomsky used language to illustrate how Cognitive Science should be conceived, namely, as the discovery of the computations underlying domains or faculties. His formulation highlights the innate dispositions that are responsible for most faculties that are specific to the human species. Chomsky became the advocate of the view that innate dispositions are essential to explain mental life and, in particular, language learning. Much of the recent work by experimental cognitive scientists corroborates his views.

Some psychologists were initially suspicious about Chomsky's proposals. Indeed, the notion that language is an instinct seems to imply that language is not learned, and this seemed absurd. How could one imagine that language is as stereotyped and rigid as the dance performed by bees to signal for food? Instincts, we are told, are narrow, species-specific behaviors essential to the survival of the species. Language, in contrast, has to be learned by everyone. Moreover, there are a great many different languages and it is difficult to imagine the evolutionary account for such a variety. Supporters of Chomsky's position pointed out that language is a unique aptitude that only our species can master. Behaviorists rejected the evidence and attempted to show, without much success, that even chimps can learn language under favorable conditions. These debates have not abated yet but Chomsky's proposals have encouraged several psychologists to investigate the infant's cognitive endowment and dispositions by using creative experimental procedures. Over the years, the results that have become available have changed the general climate so that today few are those who deny the uniqueness of language to our species. Although associationist theories went through a period of decline they are currently making a strong comeback (Elman et al., 1996; McClelland & Rumelhart, 1986) .

We will begin by reviewing investigations that have tried to determine whether humans have a specialized organ to acquire and represent language. Next, we will review some of the dispositions that infants bring to the language acquisition situation and describe how these are refined throughout the first year of life. We close our presentation of experimental investigations by arguing that languages can be clustered into classes according to their prosodic and, in particular, rhythmic properties. We will propose that rhythm is one of the essential properties initially represented by infants when they are confronted with speech utterances. Finally, we speculate about the role played by those classes in language acquisition.

INVESTIGATING THE BIOLOGY OF LANGUAGE.

The publication of Chomsky's Syntactic Structure in the mid-fifties influenced a number of psychologists. Among them was Lenneberg, who published his influential book «Biological Foundations of Language» (Lenneberg, 1967) to challenge the dominat anti-biological stance that had taken over most of psychology during the first half of the XXth century. Lenneberg, was familiar with Chomsky's critique of empiricism (Chomsky, 1957 ; Chomsky, 1959) and supplemented it with a rich description of the biological foundations of language. He presented overwhelming evidence that language is unique to the human species. Furthermore, he documented a fact that had been generally disregarded, namely, that learning language cannot be correlated with the learner's intelligence. Indeed, Lenneberg showed that children born with a very low IQ, for instance or children with Down’s syndrome, acquire language at the same pace as children with average IQs. Likewise, children with very high IQs do not learn language faster than the average. Lenneberg’s book was so influential that it altered the standard ways of thinking in psychology and neuropsychology. A few years after its publication there were complaints that the book was just a trivial itemization of well known truths, a tribute to its influence.

Lenneberg listed criteria for evaluating whether a faculty is largely genetically controlled or is acquired anew by each individual. He argued that a faculty that is present in all members of a species, in spite of considerable environmental differences, is likely to contain a fair amount of genetic determination. Moreover, genetic determinism is even more likely if a specific organ can be linked to the faculty in question. The expression of a faculty, however, even when largely determined by genetics, is modulated by the environment.

Lenneberg provided evidence that children learn language spontaneously and apparently without effort. Language arises in the deaf (Klima & Bellugi, 1979) and the blind (Landau & Gleitman, 1985) in spite of very deprived input. Even more remarkable is the fact that even some children who are congenitally both deaf and blind can acquire language using the Tadoma method based on touch (see Chomsky, 1986). The fact that children can learn language with such an impoverished sensory input suggests that the brain is pre-programmed to acquire the structures that the community uses to package grammatical systems. How this happens is a crucial aspect of the research that is being carried out by psycholinguists.

Language takes many different forms in speakers from different communities. There are thousands of languages in the world, but one can only understand the languages one has learned. Clearly, every language must be learned and humans are the only animals who have the ability to learn them. Hence, Chomsky postulates a special human endowment, the « language acquisition device » (Chomsky, 1968). Contrary to the view that language is a code that has to be learned arbitrarily by each speaker, Chomsky demonstrated that remarkable underlying regularities are shared by all languages in spite of huge superficial differences. As Chomsky states in the present volume:

…The obvious approach was to try to abstract general properties of the complex states attained, attribute them to the initial state, and show that the residue is indeed simple enough to be acquired with available experience. Many such efforts more or less crystallized 15 to 20 years ago in what is sometimes called the «principles and parameters» approach. The basic principles of language are properties of the initial state; the parameters can vary in limited ways and are set by experience....

Chomsky has argued that we grow up in surroundings that are too impoverished to allow us to privilege the view that the child learns syntax solely by extracting regularities in the input received. The solution to the child’s quandary is presented in the principle and parameters proposal. Without elaborating on this proposal we can simply say that UG is equipped with switches that can be set to specify a syntactic property of a given language. A relatively restricted number of binary parameters are supposed to specify syntactic differences between the grammars of all natural languages. The above quote illustrates the motives behind the work that many linguists and psycholinguists have pursued over the past few years.

AN ORGAN FOR LANGUAGE?

Since Broca's famous 1861 communication psychologists and neuropsychologists have devoted considerable time and effort on trying to discover whether there is a language organ located in the human brain. After reviewing the evidence available in the mid sixties, Lenneberg reached the conclusion that the brain is not specialized at birth i.e., that any of its parts can learn to accomplish a given task, including language, given the proper conditions. Lenneberg scrutinized the aphasiological data available at the time and discovered that there was a consensus attributing language to the left hemisphere in adults, but not in children under the age of four. He correlated this observation with the emergence of foreign accents and other difficulties encountered by people who learn a foreign language after puberty. From these observations Lenneberg concluded that the association of the left hemisphere with language is an epiphenomenon due to the mode and the timing of language acquisition, a view that Bever (1980) has also defended. Woods and colleagues (Woods & Teuber, 1978 ; Woods & Carey, 1979) critically reviewed the data on which Lenneberg based his conclusions and surveyed several studies that had been carried out since. They concluded that the incidence of aphasias following a right-hemisphere lesion in right-handers is similar in young children and adults. Moreover, recovery of language is not as total as had been claimed. Thus, Lenneberg's conclusion that language delays or aphasia are equally likely in very young children following right or left brain injuries has not received unconditional support. Twenty years later the association of language with the left hemisphere in young children remains unclear. For instance, Aram, Meyers and Ekelman (1990) found that both right and left lesions, produced more non-fluency in patients compared to matched controls. Indeed, recent reports from Vargha-Kadhem's and Bates' laboratories (see Muter, Taylor, & Vargha-Khadem, 1997; Reilly, Bates, & Marchman, 1998) suggest that Lenneberg's view may be closer to reality than the more recent revision.

Fortunately, in the last twenty years new methods have become available that are helping us to understand the emergence of language and hemispheric lateralization. For instance, Muller and colleagues (Muller et al., 1998) have used PET with young children who had suffered early unilateral lesions. They found evidence that the right hemisphere takes over some of the functions of the damaged left hemisphere and also that there is very little intra-hemispheric reorganization, where other areas in the left-hemisphere would take over the function initially devoted to the peri-sylvian region. This kind of study will allow us to gain a better understanding of initial brain organization, plasticity and structural determination. In the meantime, other methods have become available and suggest an initial specialization of the left hemisphere for language. Indeed, dichotic-listening experiments carried out on neonates reveal that, even at birth, humans show a disposition to process and represent language-like stimuli preferentially with the left hemisphere. This does not apply to other acoustic stimuli. Dichotic-listening tasks have been used to study language lateralization in adults and the outcome is generally that most right handed adults have a right-ear advantage for syllables or words and a left-ear advantage for music-like sequences. Best, Hoffman, & Glanville (1982) used dichotic presentations in conjunction with heart-rate orienting reflex on four-month-old infants and found that they have a right-ear advantage for language-like stimuli and a left-ear advantage for music-like stimuli. Bertoncini and colleagues (1989) also used dichotic presentation in conjunction with the non-nutritive sucking paradigm to test neonates. Using syllables, they found a right-ear-advantage when the syllable in the right ear changes but no advantage for a change in the other ear. With music stimuli a left-ear advantage was observed when a change intervened in the right ear. Segalowitz and Chapman (1980) and Molfese (1984) among others, have reported results suggesting that in very young infants and in neonates, the left hemisphere is specialized for the processing of language-like contrasts but not for other acoustic stimuli. If anything, the opposite is true for the right hemisphere. Of course, none of these experiments have the precision and reliability to inspire much confidence.

Studies using improved behavioral methods coupled with brain imaging would be helpful here. One study that has gone in this direction has been carried out by Dehaene-Lambertz and Dehaene (1994) using ERPs. They observed a greater left-hemisphere response to a phonetic contrast (ba/ga). However, in more recent studies using the same technique, Dehaene-Lambertz (in press) explicitly compared the electrical responses to linguistic and non-linguistic changes (using syllables and tones) and observed a greater left-hemisphere response in both conditions, although different neuronal networks within the left-hemisphere handled the phonetic and timber changes. This technique thus suggests an early intra-hemispheric specialization, but no language-specific left advantage. One should note however that imaging studies with adults were able to uncover a strong asymmetric activation for syllables and words only when the stimuli were presented dichotically. Binaurally presented words did not give rise to a left-hemisphere advantage (O'Leary et al., 1996). It is thus possible that, were the baby experiments carried out with dichotic stimulation, a left-hemisphere advantage would arise for syllables. The advent of improved brain-imaging technology that makes the study of neonates possible will advance our understanding of the brain structures programmed for the acquisition of language. As the above review shows, an intrinsic relation between the left hemisphere and language may be pre-programmed, although better studies will have to be carried out before we can understand how brain structures support a given faculty of mind.

With the above background information we can now turn to another claim made by Lenneberg, namely, that the older we get the harder it is to learn a language. If there is a critical period for learning language, then three consequences should arise. First, once language is acquired the initial plasticity of brain structures vanishes and that there is therefore a greater risk of a permanent language deficit following a brain lesion. Second, as brain structures become less flexible, the ability to acquire a new language diminishes. One estimates that this claim must be right every time one hears a speaker who acquired a second language late in life. Third, individuals who did not learn their first language in the crib should encounter difficulties. What happens in those rare cases when a first language is acquired late in life? An interesting review of a few feral children appeared in Brown's book *Words and Things* (Brown, 1958). Curtis also published a book about Genie, a feral child found when she was fourteen years old. Feral children, however, are not necessarily a good source of information about late first language acquisition since they have been deprived of so much for so long (including social interaction and proper care) that several different problems may be at the root of the observed deficits. Recently, Mayberry and her colleagues studied a population of deaf infants born to hearing parents (Mayberry, 1989; Mayberry, 1993). This population gained access to sign language rather late but, in contrast to feral children, had been raised raised under favorable social and emotional conditions. Mayberry and colleagues found that such children don't become as proficient as children who have learned their first language in the first two years of life. Why should this be? We usually observe more and better learning at the accepted school or University ages than in the crib. These data suggest that language-learning is a special kind of learning, and that it occurs best during the first few years of life.

Can we speak of a critical age or period after which it is very difficult and unnatural to acquire language? Or rather, should we talk about a window of opportunity or a period of life when, all other things being equal, it is easier to acquire language? If so, how long does this window remain open for language ? The evidence bearing on the acquisition of a second language is fairly clear, or at any rate, much better than that for a first language. This is due to the fact that modern life favors the acquisition of more than one language and it is easy to find highly proficient speakers of more than a single language. It is difficult, however, to assess whether speakers are as good at their first as at their second language. Indeed, careful psycholinguistic assessments have shown that in general, one language becomes dominant (Cutler, Mehler, Norris, & Segui, 1989). Second languages learned late are usually spoken with a foreign accent, and perceived via the phonology of the first language (see Dupoux, Kakehi, Hirose, Pallier, & Mehler, sous presse; Dupoux, Pallier, Sebastian-Gallés, & Mehler, 1997). Problems with morphology and syntax (see Weber-Fox & Neville, 1996) are also frequent sequels to late learning.

The later in life one learns a second language, the more pronounced the foreign accent. As we mentioned above, we are not sure that there really is a *critical age* for language acquisition[1]. Flege, Munro, & MacKay (1995) have shown that pronunciation of a second language acquired after the age of three is increasingly deviant[2]. They have claims that poor pronunciation of the second language is inversely related to age of acquisition but more research would be needed to ground such an assertion. Individual differences in the ease with which one acquires a foreign language may be important. Likewise, comprehension and production routines may have different windows of opportunity across speakers. In a study that focused on syntactic and semantic rather than on phonological aspects, Weber-Fox and Neville (1996) showed that Chinese immigrants, who daily speak English more than any other language, perform less well than native speakers of English. This observation is valid even for immigrants who began speaking English before the age of three.

Speech perception itself seems to get adjusted to the first language acquired, not the second one, even it it is acquired very early (between ages 3-6 years). Thus, Pallier et al. (1998) studied highly bilingual adults, who had been exposed to Spanish and Catalan from early childhood (with exposure to the second language starting between the ages of 3 and 6). They showed that subjects did not organize their vocalic space in the same way if they had acquired Spanish before Catalan or vice-versa. The findings by Cutler et al. (1989) with highly proficient English-French bilinguals point in the same direction. Although all the subjects they tested felt equally fluent and at ease in both languages, they were able to split the group into French-dominant and English-dominant subjects and observe different behaviors for the two populations. Subjects behaved either like English monolinguals or French monolinguals but could not change their processing mode to match the language that was presented.

These and other studies suggest that the ability to acquire a language decreases with age. It is, however, unclear whether the capacity to learn decays gradually or abruptly. Only in the latter case would one be entitled to speak of a critical age per se. Regardless of the ultimate outcome of these investigations it seems judicious to speak of a window of opportunity for learning a language and securing a performance close to the performance we observe in matched monolinguals. This conclusion is close to Lenneberg’s conjecture.

Brain-imaging studies have complemented the above explorations of bilingual processing. Positron Emission Tomography (PETscan) and functional Magnetic Resonance Imaging (fMRI) have made it possible to explore the cortical representation of first and second languages in healthy bilinguals. In a series of experiments, bilingual subjects were selected so that the age of

[1] This is true whether one is talking about learning the first or a second language.
[2] We don’t know whether this would also be the case for the first language.

second language acquisition, the proficiency attained, and the distance between the first and second language were varied. A number of studies have shown that the first language is bilaterally represented in the peri-sylvian cortex across different languages. In all studies, however, a clear left hemisphere dominance for the first language was observed (see Dehaene et al., 1997 ; Mazoyer et al., 1993 ; Perani et al., 1996 ; Perani et al., 1998). Moreover, the cortical representation of the second language varies greatly in high- and low-proficiency bilinguals : In low-proficiency bilinguals, representation of the second language is very variable from one subject to the next, some subjects even having the second language predominantly represented in the right hemisphere (Dehaene et al., 1997) ; In high-proficiency bilinguals, in contrast, the first and second languages occupy the same cortical regions of the left hemisphere, apparently irrespective of age of acquisition in the current studies (Perani et al., 1998).

The above studies used Spanish-Catalan, Italian-English, and French-English bilinguals. Even though Spanish and Catalan may be closer to each other than the other members of the language pairs, in all cases the languages involved were fairly closely related. What would happen if one studied bilinguals who spoke extremely distant languages? This question was partially answered in a study by Kim and colleagues (Kim, Relkin, Kyoung-Min, & Hirsch, 1997). They explored implicit speech production in bilinguals from a variety of languages and found results that are comparable to the ones mentioned above. In contrast, Neville et al. (1998) studied high proficiency bilinguals who spoke both English and American Sign Language (ASL), two languages that differ even in the modality involved (auditory vs visual) and found that the representation of English and ASL remain only partially similar in spite of the fact that the bilinguals were as proficient as the Spanish-Catalan bilinguals mentioned above. As Paulesu and Mehler (1998) have argued, more research is needed to understand whether bilinguals who speak an oral language and ASL constitute a special case or not when compared to people who speak two oral languages. Further research should clarify the variables that determine the cortical representations of the first and second language in the bilingual.

In summary, when the first language is acquired in the crib it is mastered to perfection, baring neurological deficit. In contrast, when it is learned after the age of three the competence attained differs from the norm. It remains unclear whether the difficulties with a second language learned after the age of two or three are due to interference from the first language or to the closing of the window of opportunity. One way to answer this query may be through the study of infants exposed to two languages from the onset of life. We might conjecture that such bilinguals acquire two maternal languages. In contrast, if these infants do not master both languages equally well we might hypothesize that this is due to reciprocal interference. A way to address this issue is to study adults who have forgotten their first language (for instance, children adopted outside their linguistic community). In such cases, the first language is not active when the second is acquired and therefore cannot interfere with the second language. Data from both research lines is now starting to be gathered, and we may hope to know more about these issues presently. Meanwhile, to the question «How young is the infant when the first adjustments to the surrounding language are made?» we can now answer that language acquisition begins with the learner’s first exposures to linguistic signals.

FIRST ADJUSTMENTS TO THE MATERNAL LANGUAGE:

Two months before birth and thereafter, infants encounter all kinds of noise, including that made by other humans' vocal tract. It seems reasonable to speculate that nature provides our species with the means of identifying stimuli that are relevant for language learning from other incoming stimuli. Other animals also have specific mechanisms to recognize sounds made by conspecifics. Researchers have questioned whether humans prefer language-like sounds to other sounds (see Colombo & Bundy, 1983). Whatever the findings may be they lend themselves to many different interpretations. Preference studies like these leave open the possibility of finding a non-linguistic sound that infants may prefer to utterances produced by a speaker. Even though it is, to say the least, difficult to know what auditory stimulus an infant prefers, we know that infants are particularly well equipped to process speech sounds. In particular, infants have the ability to establish that utterances belong to the same language. This finding has been central to our preoccupations for a long time.

A decade ago it was discovered that neonates react when a speaker suddenly switches from one language to another (Mehler et al., 1988). Although in maternity wards anecdotes were being told that when their foreign mother switched to French, infants often showed signs of distress, these stories were dismissed. However, during the second half of the eighties newborns were tested with natural sentences to try and understand at what point in development they act as if they knew that sentences belong to an abstract construct, namely, a natural language. Research in the visual modality has uncovered that rather early in life infants represent visual objects as belonging to natural categories (Quinn, Eimas, & Rosenkrantz, 1993), and it is equally likely that before the first year of life they also represent a language as a natural category.

Research was carried out with neonates who were confronted to their parental language after they had listened to a foreign language. Their reaction to the language switch was compared to that of control infants who were tested with a novel set of sentences in the same language as the one to which they had been habituated. The results of this study established that neonates distinguish a change in language. The discrimination response persists when the sentences are low-pass filtered but vanishes when they are played backwards[3]. Mehler et al. concluded that infants are attending to acoustic cues that differ for French and Russian, the languages that were used in the study. Studies presented in the same paper also showed that neonates born in France, to French speaking parents, distinguish sentences in English from sentences in Italian, languages to which they had never been exposed prior to the experiment (see Mehler & Christophe, 1995). This suggests that infants do not need to be familiar with one of the languages in the pair to react to a shift. We take these results as an indication that discrimination is facilitated by salient acoustic properties of the languages rather than only by experience[4].

What are the limits of this ability to distinguish pairs of languages? Which cues determine its fulfillment and what role, if any, does it play in the course of language acquisition? The first question is rather rhetorical since, from the outset, it did not seem likely that infants could notice a switch between any two languages randomly drawn from the thousands of inventoried languages. In fact, adults often fail to notice when someone switches from one foreign language to another unknown language. Why then, can one ask, would infants do better than adults?

[3] As was mentioned before, it is difficult to judge whether infants prefer linguistic stimuli to other acoustic sounds. Backward speech is however an excellent stimulus to contrast with speech. It has the same spectrum as speech but backwards. Nonetheless, infants show sophisticated behaviors to speech that they fail to display with backward speech.

[4] Some investigators, (Mehler et al., 1988; Moon, Cooper, & Fifer, 1993) and others have also found that neonates prefer the language in the surrounds to an unfamiliar language. These studies suggest that during the first days of life and/or the last two months of pregnancy, the infant is already sensitized to some properties of their «native» language.

Rather, it seems more likely that infants, like adults, will miss some shifts while readily detecting others. Thousands of languages are spoken around the world making it impossible to explore the infants' behavior systematically. Fortunately, some clear cases of failure were first noticed and then reported by Nazzi, Bertoncini and Mehler (1998). They found that French neonates distinguish Japanese from English although they fail to discriminate Dutch from English. These contrasting results indicate that to newborn babies' ears, Dutch and English are more similar than Japanese and English. Mehler, Dupoux, Nazzi, & Dehaene-Lambertz (1996) have suggested that prosodic properties of languages, and in particular rhythmic properties, may be most salient to very young infants, and would form the basis of the first representations infants build for speech signals. Before we spell out this proposal in more detail, we will examine how the language discrimination ability evolves during the first few months of life.

Two- to three-month old American infants discriminate English from Italian (Mehler et al., 1988) and English from French (Dehaene-Lambertz & Houston, 1998). Once again, performance is preserved with low-pass-filtered sentences, indicating that the discrimination is made on the basis of prosodic properties of the speech signal. Dehaene-Lambertz, in addition, showed that the discrimination collapsed when the speech signals presented to the infant were shorter than phonological phrases. However, one striking behavioral change was observed between birth and 2-3 months of age : two-month olds, in contrast to neonates, fail to notice a language switch between two foreign languages. Already in the first study (Mehler et al., 1988) it was noted that two-month-old American infants failed to discriminate Russian from French, even though neonates reacted to the very same sentences. Similarly, English-born infants failed to discriminate French from Japanese, two very different foreign languages, even though they were able to discriminate English from Japanese (Christophe & Morton, 1998)[5]. In contrast, as mentioned above, French neonates were able to detect a change from English to Italian (Mehler et al., 1988) or from Japanese to English (Nazzi et al., 1998). This behavioral change that takes place during the first two months of life may be the one of the earliest adjustment the infant makes in response to the maternal language. Both Werker and her colleagues (Werker & Polka, 1993; Werker & Tees, 1984), and Kuhl and her colleagues (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992) showed that infants start to specify the phonemes of their language between 6 and 12 months of age, when their behavior becomes similar to that of adults from their maternal language. Now we know that it takes infants barely two months to make an initial adjustment to the «native» language. We take this adjustment to involve the identification of some characteristic prosodic properties of their maternal language. Those are the properties that attract the infants' attention.

What happens with language pairs that newborns cannot distinguish ? Christophe and Morton (1998) found that two to three months old British infants are marginally significant with both a switch between English and Dutch, and between Japanese and Dutch. They interpreted this result as indicating that some babies of that age still confound Dutch and English (therefore failing in the Dutch-English comparison, but succeeding in the Dutch-Japanese one, since it becomes a native vs foreign distinction) while others have already decided that Dutch sentences are non-native (therefore succeeding in the Dutch-English comparison but failing in the Dutch-Japanese one, which involves two foreign languages). Consonant with this interpretation, Nazzi

[5] Note that for this conclusion to be fully warranted, one needs to obtain the reverse pattern of results with French babies: namely, discrimination of French/Japanese, but no discrimination of English/Japanese (two foreign languages for the French babies). To date, an attempt to obtain French-Japanese discrimination with French babies has failed (French babies also did not discriminate between English and Japanese). This experiment is currently being replicated.

and Jusczyk (submitted) observed that when they reach 5 months of age, a group of American infants successfully distinguish between English and Dutch.

More data on this issue come from studies carried out in Barcelona with Spanish and Catalan using the same technique as Dehaene-Lambertz and Houston (1998). These two languages appear to be also very close prosodically, possibly as close as English and Dutch. Bosch and Sebastian-Galles (1997) observed that 4-month-old Spanish babies (that is, born in Spanish-speaking families) were able to distinguish between Spanish and Catalan : specifically, they oriented faster to Spanish, their native language, than to Catalan ; symmetrically, Catalan babies oriented faster to Catalan than to Spanish. In addition, preliminary results suggest that French newborns are unable to distinguish between Spanish and Catalan sentences (Ramus et al., in preparation). These results thus suggest that by 4 months of age, infants who have had some experience with at least one of the languages involved are able to perform finer discriminations.

The data we have presented so far suggest that babies are able at birth to distinguish between pairs of languages that are sufficiently different prosodically, even when none of these languages is familiar to them. This suggests that they are endowed with an ability to represent languages. During the first few months of life, babies refine their representation of their mother tongue and lose the ability to distinguish between two foreign languages, while they gain the ability to distinguish their mother tongue from foreign languages which are similar to it. What might be the use of such a representation? We suggest that infants may use it to discover some of the phonological and syntactic properties of their maternal language. This view is consonant with the « prosodic bootstrapping » approach which has been initially advocated by Gleitman and Wanner (1982). More recently, Morgan coined the term « phonological bootstrapping » (Morgan & Demuth, 1996) to convey the idea that some formal properties of languages, either phonological or syntactic, can be discovered through a purely phonological analysis of the speech input, without reference to, for instance, the context in which utterances are spoken.

One extreme example of such a view suggests that babies might decide about the word order of their native language by listening to its prosody (Christophe, Guasti, Nespor, Dupoux, & van Ooyen, 1997; Nespor, Guasti, & Christophe, 1996). In human languages, either complements consistently follow their heads, as in English, French or Italian, or they consistently precede them, as in Japanese, Turkish or Bengali. The first set of languages are called « Head-Complement », the second Complement-Head. In Head-Complement languages, the main prominence of each phonological phrase (a small prosodic unit generally containing one or two content words) falls on its last word, while it falls on the first word in Complement-Head languages. As a consequence, if babies can hear prominence within phonological phrases, they might use this information to decide about the word order of their native language. To gather empirical support for this hypothesis, we used sentences in French and Turkish, two languages that are very well matched for a number of prosodic features (such as syllabic structure, word stress, absence of vowel reduction), but differ in their head direction. A first experiment found that 2-month-old babies could distinguish between sentences in French and Turkish on the basis of their prosody alone, suggesting that babies this age can hear the difference of prominence within phonological phrases (Guasti, Nespor, Christophe, & van Ooyen, in press). Further experiments are in progress to confirm this result.

Before we end this section, we wish to present some more empirical data on how much of the phonology of their native language children acquire before they reach the end of their first year of life. Peter Jusczyk and his colleagues have shown, for instance, that American babies know about the preferred stress pattern for words of their language by the age of 9 months (Jusczyk, Cutler, & Redanz, 1993a). Also at 9 months, babies prefer to listen to native words than to words which either contain either non-native phonemes, or illegal strings of phonemes (Friederici & Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993b; Jusczyk, Luce, & Charles-Luce, 1994). During the last few months of the first year of life, babies also show some ability to recover spoken words from whole sentences (Jusczyk & Aslin, 1995; Jusczyk, Houston, & Newsome, in press). To this end, they may use both their knowledge of typical word patterns and phonotactics, as well as an ability to compute distributional regularities between strings of adjacent phonemes or syllables (Brent & Cartwright, 1996; Morgan, 1994; Saffran, Aslin, & Newport, 1996). Finally, there is evidence that by the age of 10 to 11 months, infants may already know some of the function words of their language, since they react to their replacement by nonsense words (Shafer, Shucard, Shucard, & Gerken, 1998).

Taken together, these results (and many others) suggest that when they reach the end of their first year of life, babies have acquired most of the phonology of their mother tongue. In addition, it seems that phonology is acquired before the lexicon contains many items, and in fact helps lexical acquisition (for instance, both phonotactics and typical word pattern may help segmenting sentences into words), rather than the converse, whereby phonology would be acquired by considering a number of lexical items. Therefore, one is led to wonder how infants may learn about the phonological properties of their mother language, in the absence of a sizeable lexicon. One may think that the path to learning phonology is simple, and not different from the acquisition of many other skills. This may indeed be true of certain properties that are evident on the surface, like rhythm. However, other phonological properties may not be accessible through a direct analysis of the speech signal, and may therefore need to be bootstrapped, much in the way already proposed for certain syntactic properties. We now present a possible scenario of this sort.

THE PHONOLOGICAL CLASS HYPOTHESIS.

In the previous section we have reviewed the remarkable ability of newborns to discriminate between languages. Here, we would like to emphasize that what is even more remarkable is that they don't discriminate all possible pairs of languages. Newborns have been shown to discriminate between French and Russian, English and Italian (Mehler et al., 1988), English and Spanish (Moon et al., 1993), English and Japanese (Nazzi et al., 1998), Dutch and Japanese (Ramus et al, in preparation), but not between English and Dutch (Nazzi et al., 1998) nor Spanish and Catalan (Ramus et al, in preparation).

Moreover, Nazzi et al (1998) showed evidence of discrimination between *groups of languages*. They habituated one group of French newborns to a mixed set of English and Dutch sentences, and tested them with a set of Spanish and Italian sentences. Another group was habituated to English and Italian, then tested with Dutch and Spanish. What Nazzi et al discovered is that only the former group reacted to a change in the pair of languages. That is, newborns reacted as if they perceived English and Dutch as belonging to one family, and Spanish and Italian as belonging to another one. On the other hand pairing English with Italian and Dutch with Spanish didn't seem to elicit any discrimination behavior.

All these studies concur to suggest that infants may represent languages in a space where English is closer to Dutch than to Spanish or Italian, and so forth. This is strongly reminiscent of the typological research done by linguists like Pike or Abercrombie. Pike (1945) suggested that languages can be classified into two major classes on the basis of the units of time on which these languages rely: they described Romance languages, as well as Yoruba and Telegu as syllable-timed, and Germanic and Slavic languages, as well as Arabic, as stress-timed languages. Pike and also Abercombie (1967) believed that syllable-timed languages have syllable isochrony and stress timed languages have inter-stress intervals that are isochronous. Since then, this typology was expanded by Ladefoged (1975) who argued that languages like Japanese (or Tamil) have mora-timing.

This typology suggests that newborns could in fact be sensitive to the rhythmic properties of languages, and classify them with respect to their rhythm type. All the studies reviewed above are indeed consistent with the view that infants primarily discriminate between languages presenting different types of rhythm, and confound languages sharing the same type of rhythm. We conjecture that in such experiments, the infant first identifies the rhythm class of the utterances, and is then able to detect large deviations in rhythm when listening to utterances that belong to another class.

However, the very notion that languages can be grouped into a few rhythm classes is not uncontroversial. Indeed, the linguistic intuitions were not corroborated by subsequent precise measurement. Phoneticians have consistently failed to find empirical evidence for the isochrony hypothesis. Some investigators have suggested that languages cannot be sorted into groups since their properties vary almost continuously (Nespor, 1990). Today, a consensus has been built around the notion that languages do not cluster at all. In contrast, we will attempt to defend the opposite view with recent evidence that favors the acoustic/phonetic reality of the rhythm classes.

Ramus, Nespor and Mehler (in press) explored in great detail the proposal that neonates begin by representing utterances as a succession of vowels (Mehler et al., 1996). According to this view, the quality of the vowels is ignored; only their duration and energy are mapped onto a grid. In between vowels the infant represents the distance between the offset of a vowel and the onset of the following one. Using a large corpus of utterances in eight different languages[6], Ramus et al studied all utterances measuring the duration of vowels and the duration of the intervening time taken up by consonants. Next, a simple calculation allowed to determine, for each utterance and each language, the proportion of time taken up by vowels (%V), the standard deviation of the vocalic intervals (ΔV) and the standard deviation of the consonantal intervals (ΔC).

[6] The languages were four syllable-timed languages, French, Spanish, Italian and Catalan; three stress-timed languages, English, Polish, and Dutch; one mora-timed language, Japanese.

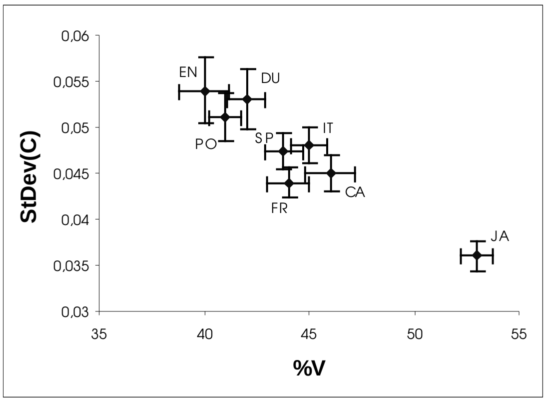

Fig 1. Average %V and ΔC for each language. Error bars represent +/-1 standard error of the mean, over 20 three-second-long sentences per language. From Ramus, Nespor & Mehler (in press).

As can be seen in Fig. 1, when %V is plotted against ΔC the languages pattern in a way that is compatible with the rhythm classes. Indeed, the four syllable-timed languages cluster together. The three stress-timed languages are next to one another but separate from the syllable-timed languages. Japanese appears as a singleton in another part of the graph.

More than a graphical representation of the three rhythm classes, these data allow, through simulations and statistical tests, to correctly predict the results observed in language discrimination experiments (see Ramus et al, in press). Thus, even though the number of languages studied is small, we find in these data good reasons to believe that rhythm, conceived as the alternation of vowel and consonant duration, is an essential property that makes it possible to discriminate languages. We are also confident that, thanks to their sensitivity to rhythm, infants can classify languages into a few rhythm classes.

This leads us to formulate the Phonological Class Hypothesis[7] (PCH): we propose that the rhythm classes are in fact phonological classes, in the sense that they group languages that share a number of phonological properties, rhythm being only one of them. The privileged role of rhythm lies in the fact that it is the property that is most readily perceived by infants, possibly enabling them to acquire the other properties.

So what are these other properties that are tied to rhythm? The linguistic literature provides a wealth of possible candidates. At the present state we can elaborate on only one such scenario, which was originally proposed by Ramus et al (in press). Syllable complexity seems to be a parameter that is firmly tied to speech rhythm. Indeed, linguists like Bertinetto (1981), Dasher (1982) and Dauer (1983) had already noticed that stress-timed languages allow syllables that are more complex than in syllable-timed languages, and a fortiori than in mora-timed languages. Different degrees of syllable complexity are even invoked as the cause for the different types of rhythm. This is mostly evident in Figure 1, since the variables %V and ΔC actually are correlates of syllable complexity: stress-timed languages, having more complex syllables, have more consonants in their syllables, thus lower %V. At the same time, they also allow simple syllables, which means that the size of consonant clusters is more variable, hence higher ΔC.

Thus, it is clear that an early determination of the rhythm class can enable infants to partly specify the syllables of their native language. Note that this is true regardless of the linguistic

[7] An earlier version called "the periodicity bias" can be found in (Cutler & Mehler, 1993).

theory one uses to describe syllable structure. Within the Principles & Parameters framework (Chomsky, 1981), infants can use rhythm class as a "trigger" (Gibson & Wexler, 1994) to set parameters like Complex-onset and Complex-coda. This aspect can be equally well captured within Optimality Theory (Prince & Smolensky, 1993), where markedness, thus syllable complexity, is directly apparent in the level of faithfulness constraints with respect to structural constraints. In this formulation, knowing the type of rhythm can enable to set the faithfulness constraints right at the appropriate level. This is corroborated by typological work from Levelt and Van de Vijver (1998), who have proposed 5 levels of markedness for syllable structure, 3 of which seem to correspond to the current rhythm classes, the other two possibly falling in-between.

The Phonological Class Hypothesis has been presented to account for the earliest adjustments infants make during language acquisition. In addition to its value as an account of language learning, PCH may also explain some properties of the adult speech processing system. For instance, when exposed to highly-compressed speech (up to 50%), subjects find it very difficult to understand them at first, then they gradually improve and finally reach asymptotic performance after a dozen sentences (Mehler et al., 1993; Voor & Miller, 1965). Furthermore, this performance seems to transfer across speakers (Dupoux & Green, 1997) and languages (Mehler et al., 1993; Pallier, Sebastian-Galles, Dupoux, Christophe, & Mehler, 1998). The interesting point is that transfer seems to occur only between languages belonging to the same rhythm class. This suggests that the mechanisms that enable listeners to normalize for speech rate may depend of the phonological class of the language. More research is now needed to understand the precise nature of these mechanisms and in which respect they depend on phonological classes. But this last example allows us to conjecture that the Phonological Class Hypothesis might have a much broader scope than just being a bootstrap for the acquisition of syllable structure.

CONCLUSION:

Exploring the earliest stages of language acquisition, we believe, is an essential ingredient to uncover how language is learned. To make this point, we first asserted that Chomsky transformed the study of language acquisition by formulating a detailed theoretical framework to understand how the child learns the grammar of the maternal language. Next, we showed that nativism, an essential ingredient to his formulation, was consistent with the discoveries made by scientists focusing on the biological foundations of language. This state of affairs stimulated the progress observable since the mid-sixties and led to a fairly broad rejection of the empiricist position that reigned over most of the first part of the century. Today, it is difficult to find impartial scientists who think that the linguistic competence is equally shared by humans and animals. We were less outright, however, when trying to identify the locus of the postulated language organ. We closed our presentation showing that infants display behaviors that are remarkably well suited to acquire language. These behaviors can already be exposed in neonates during their first contacts with speech. We are not, however, claiming that those behaviors are unique to humans. We only claim that it is only humans who enact them and derive language as a consequence.

What lessons are cognitive scientists to draw from the facts presented above? We think that they have contributed to question the validity of the traditional learning models that psychologists adopted to explain language acquisition. As we mentioned in our introduction, standard learning models are usually invoked to explain how infants acquire their native language. In fact, those models suppose that the native language and the languages that are acquired later in life are learned in the same way. Mostly, learning models assume that one learns by forming associations between stimuli or between behavior and stimulating configurations. As a corollary, statistical regularities in the surrounds are viewed as allowing associations to grow in strength.

Gallistel (1990) has argued that there is more than association that is needed to explain learning. He showed that animal psychologists have failed to explain species-specific behaviors through associations. Explaining species-specific behaviors, according to him, requires models that involve counters, timers and comparators, devices that do not enter into associative models. In Gallistel's view that is precisely the source of their failure and the reason to induce psychologists to seek more powerful learning algorithms. This is a very similar message as the one that Chomsky had delineated in his critique of Skinner (Chomsky, 1959). Possibly, the surprise that psychologists felt when they discovered that children learn the lexicon in a non-monotonic fashion derives from the fact that implicit models for language acquisition are based on the idea that language is learned by association. Language learning, even learning the words that belong to the lexicon may require specialized learning routines that are not applied to others kinds of learning. For an alternative point of view see Paul Bloom (Markson & Bloom, 1997).

Psycholinguists have shown that infants use statistical procedures to segment speech signals and learn the words in the language (Saffran et al., 1996). The fact that statistical computations are used to build language specific representations is not surprising in itself: after all, infants are trying to extract regularities from the incoming input. The essential question, however, is whether statistics are sufficient for language learning, or whether, as Chomsky and his colleagues have claimed, rules are also required. Marcus and his colleagues (Marcus, Vijayan, Bandi Rao, & Vishton, 1999) have argued that infants can use algebraic rules to characterize lexical items. In a recent paper they showed that infants who listened to tri-syllabic words continuously spoken without any prosody extract characteristic structural properties of these words. In fact, if the words have an ABB structure, i.e., repeated second and third syllables, infants treat novel ABB words as if they were familiar. Marcus concludes that infants use algebraic rule-like reasoning to extract structural representations. The work by Saffran et al. and that of Marcus et al. characterize two central learning procedures that are used by infants.

In our work we have explored a learning procedure related to Chomsky's principles and parameters view of grammar. Chomsky's proposal is that humans are born with basic notions of syntax and phonology. Furthermore, humans have parameters that allow them to determine the particular value that a property can take. We illustrated this with the Head-Complement Direction parameter and parameters ruling syllable structure. Learnability issues have bewildered psycholinguists who tried to apply the principles and parameters framework to the development of language (see e.g. Mazuka, 1996). Psycholinguists have tried to extract themselves from this quandary by proposing that phonological properties of languages provide cues to bootstrap the acquisition process (see Gleitman & Wanner, 1982; Morgan & Demuth, 1996). As we saw above, we have hypothesized that certain prosodic properties of sentences would be the perfect cue to pre-set the Head-Complement parameter (Christophe et al., 1997). The language discrimination experiments presented in the context of the Phonological Class Hypothesis can also be appraised within the phonological bootstrapping hypothesis. It seems likely that the determination of the rhythmic class will facilitate the acquisition of the sound pattern of the native language (Ramus et al., in press).

To conclude, we think that the time is now ripe to allow researchers to devise relatively specific learning algorithms, and decide empirically which one is closer to the actual developmental path followed by children. Therefore, one may hope to bring experimental answers to questions such as whether a purely statistical learning mechanism may allow the acquisition of a given part of language (say, word stress), or whether an appeal to innate language-universal constraints is necessary to account for the data. The domain of phonology, involving simpler representations than syntax and acquired first, may lend itself nicely to such an endeavor.

Abercrombie, D. (1967). *Elements of general phonetics*. Chicago: Aldine.

Adolph, K. A. (1995). Psychophysical Assessment of Toddlers' Ability to Cope with Slopes. *Journal of Experimental Psychology: Human Perception and Performance, 21*(4), 734-750.

Aram, D. M., Meyers, S. C., & Ekelman, B. L. (1990). Fluency of Conversational Speech in Children with Unilateral Brain Lesions. *Brain & Language, 38*, 105-121.

Bertinetto, P. M. (1981). *Strutture prosodiche dell' italiano. Accento, quantità, sillaba, giuntura, fondamenti metrici*. Firenze: Accademia della Crusca.

Bertoncini, J., Morais, J., Bijeljac-Babic, R., McAdams, S., Peretz, I., & Mehler, J. (1989). Dichotic perception and laterality in neonates. *Brain and Language, 37*, 591-605.

Best, C. T., Hoffman, H., & Glanville, B. B. (1982). Developmentof infant ear asymmetries for speech and music. *Perceptionand Psychophysics*, *31*, 75-85.

Bever, T. G. (1980). Broca and Lashley were right: cerebral dominance is an accident of growth. In D. Caplan (Ed.), *Biological Studies of Mental Processes* (pp. 186-232). Cambridge Ma.: MIT Press.

Bosch, L., & Sebastian-Galles, N. (1997). Native language recognition abilities in 4-month-old infants from monolingual and bilingual environments. *Cognition, 65*, 33-69.

Brent, M. R., & Cartwright, T. A. (1996). Distributional regularity and phonotactic constraints are useful for segmentation. *Cognition, 61*, 93-125.

Brown, R. (1958). *Words and Things.* New York: Free Press, Macmillan.

Brown, R. (1973). *A first language*. Cambridge: Harvard University Press.

Chomsky, C. (1986). Analytic study of the tadoma method: language abilities in three deaf-blind subjects. *Journal of Speech and Hearing Research, 29,* 332-347.

Chomsky, N. (1957). *Syntactic Structures*. The Hague: Mouton.

Chomsky, N. (1959). A review of Skinner's. *Verbal Behahior, 35*, 26-58.

Chomsky, N. (1965). *Aspects of a Theory of Syntax*: Cambridge: MIT Press.

Chomsky, N. (1968). *Language and Mind*. New-York: Brace \& World.

Chomsky, N. (1981). *Lectures on Government and Binding*. Dordrecht: Foris.

Christophe, A., Guasti, M. T., Nespor, M., Dupoux, E., & van Ooyen, B. (1997). Reflections on phonological bootstrapping: its role for lexical and syntactic acquisition. *Language and Cognitive Processes, 12,* 585-612.

Christophe, A., & Morton, J. (1998). Is Dutch native English? Linguistic analysis by 2-month-olds. *Developmental Science, 1*(2), 215-219.

Colombo, J., & Bundy, R. S. (1983). Infant response to auditory familiarity and novelty. *Infant Behavior and Development, 6*, 305-311.

Cutler, A., & Mehler, J. (1993). The periodicity bias. *Journal of Phonetics, 21,* 103-108.

Cutler, A., Mehler, J., Norris, D., & Segui, J. (1989). Limits on bilinguism. *Nature, 340*, 229-230.

Dasher, R., & Bolinger, D. (1982). On pre-accentual lengthening. *Journal of the International Phonetic Association, 12*, 58-69.

Dauer, R. M. (1983). Stress-timing and syllable-timing reanalyzed. *Journal of Phonetics, 11*, 51-62.

Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Paulesu, E., Perani, D., van der Moortele, P. F., Lehiricy, S., & Bihan, D. L. (1997). Anatomical variability in the cortical representation of first and second languages. *NeuroReport, 8*, 3809-3815.

Dehaene-Lambertz, G. (in press). Cerebral asymetry in 2-month-olds. *Journal of Cognitive Neuroscience*.

Dehaene-Lambertz, G., & Dehaene, S. (1994). Speed and cerebral correlates of syllable discrimination in infants. *Nature, 370*, 292-295.

Dehaene-Lambertz, G., & Houston, D. (1998). Faster orientation latency toward native language in two-month-old infants. *Language and Speech*, *41*, 21-43.

Dupoux, E., Kakehi, K., Hirose, Y., Pallier, C., & Mehler, J. (sous presse). Epenthetic vowels in Japanese: A perceptual illusion? *Journal of Experimental Psychology: Human Perception and Performance.*

Dupoux, E., Pallier, C., Sebastian-Gallés, N., & Mehler, J. (1997). A destressing "deafness" in French? *Journal of Memory and Language, 36*, 406-421.

Elman, J. L., Bates, E., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development.* Cambridge, Mass.: MIT Press.

Flege, J. E., Munro, M. J., & MacKay, I. R. A. (1995). Effects of age of second-language learning on the production of English Consonants. *Speech Communication, 16*(1), 1-26.

Friederici, A. D., & Wessels, J. M. I. (1993). Phonotactic knowledge of word boundaries and its use in infant speech-perception. *Perception & Psychophysics*, 287-295.

Gallistel, C. R. (1990). *The organization of learning.* Bradford Books/MIT Press: Cambridge (MA).

Gibson, E., & Wexler, K. (1994). Triggers. *Linguistic Inquiry, 25*, 407-454.

Gleitman, L. R., & Wanner, E. (1982). Language acquisition: The state of the state of the art. In Wanner & G. E. L. R. (Eds.), *Language Acquisition: State of the Art* . New York: Cambridge University Press.

Guasti, M. T., Nespor, M., Christophe, A., & van Ooyen, B. (in press). Pre-lexical setting of the head complement parameter through prosody. In J. Weissenborn & B. Höhle (Eds.), *Signal to Syntax II* .

Held, R., Birch, E., & Gwiazda, J. (1980). Stereoacuity of human infants. *Proceeding of National Academy of Science USA, 77*, 5572-5574.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology, 29*, 1-23.

Jusczyk, P. W., Cutler, A., & Redanz, N. J. (1993a). Infants' preference for the predominant stress patterns of English words. *Child Development, 64*, 675-687.

Jusczyk, P. W., Friederici, A. D., Wessels, J. M. I., Svenkerud, V. Y., & Jusczyk, A. M. (1993b). Infants' sensitivity to the sound pattern of native language words. *Journal of Memory and Language, 32*, 402-420.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (in press). The beginnings of word segmentation in English-learning infants. *Journal of Cognitive Psychology*.

Jusczyk, P. W., Luce, P. A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language, 33*, 630-645.

Kim, K. H. S., Relkin, N. R., Kyoung-Min, L., & Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature, 388*(July 10), 171-174.

Klima, E., & Bellugi, U. (1979). *The signs of language*. Cambridge, Ma: Harvard University Press.

Kuhl, P., Williams, K., Lacerda, F., Stevens, K., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science, 255*, 606-608.

Ladefoged, P. (1975). *A course in phonetics*. New York: Harcourt Brace Jovanovich.

Landau, B., & Gleitman, L. (1985). *Language and Experience - Evidence from a Blind Child*: Cambridge Mass.: Harvard University Press.

Lenneberg, E. (1967). *Biological foundations of language*: New York: Wiley.

Levelt, C., & van de Vijver, R. (1998, 11-12/06/1998). *Syllable types in cross-linguistic and developmental grammars.* Paper presented at the Third Biannual Utrecht Phonology Workshop, Utrecht.

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

Markson, L., & Bloom, P. (1997). Evidence against a dedicated system for word learning in children. *Nature, 385*, 813-815.

Mayberry, R. I. (1989). Looking through phonological shape to lexical meaning: the bottleneck of non-native sign language processing. *Memory and Cognition, 17*, 740-754.

Mayberry, R. I. (1993). First-language acquisition after childhood differs from second-language acquisition: the case of American Sign Language. *Journal of Speech and Hearing Research, 36*, 1258-1270.

Mazuka, R. (1996). How can a grammatical parameter be set before the first word? In J. L. Morgan & K. Demuth (Eds.), *Signal to Syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 313-330). Mahwah, NJ: Lawrence Erlbaum Associates.

McClelland, J. L., & Rumelhart, D. E. (1986). *Parallel distributed processing: Explorations in the microstructures of cognition. Vol 2. Psychological and Biological Models.* Cambridge Mass.: MIT Press.

Mehler, J., & Christophe, A. (1995). Maturation and learning of language in the first year of life. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences: A handbook for the field* (pp. 943-954). Cambridge, Mass.: MIT Press.

Mehler, J., Dupoux, E., Nazzi, T., & Dehaene-Lambertz, G. (1996). Coping with linguistic diversity: The infant's viewpoint. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 101-116). Mahwah, NJ: Lawrence Erlbaum Associates.

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

Mehler, J., Sebastián-Gallés, N., Altmann, G., Dupoux, E., Christophe, A., & Pallier, C. (1993). Understanding compressed sentences: the role of rhythm and meaning. *Annals of the New York Academy of Science, 682*, 272-282.

Molfese, D. (1984). Left hemisphere sensitivity to consonant sounds not displayed by the right hemisphere: Electrophysiological correlates. *Brain and Language, 22*, 109-127.

Moon, C., Cooper, R., & Fifer, W. (1993). Two-day-olds prefer their native language. *Infant Behavior and Development, 16*, 495-500.

Morgan, J. L. (1994). Converging measures of speech segmentation in preverbal infants. *Infant Behavior and Development, 17*, 389-403.

Morgan, J. L., & Demuth, K. (1996). Signal to Syntax: an overview. In J. L. Morgan & K. Demuth (Eds.), *Signal to Syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 1-22). Mahwah, NJ: Lawrence Erlbaum Associates.

Muller, R.-A., Rothermel, R. D., Behen, M. E., Muzik, O., Mangner, T. J., Chakraborty, P. K., & Chugani, H. T. (1998). Brain Organization of Language after Early Unilateral Lesion: A PET Study. *Brain & Language, 62*, 422-451.

Muter, V., Taylor, S., & Vargha-Khadem, F. (1997). A longitudinal study of early intellectual development in hemiplegic children. *Neuropsychologia, 35*(3), 289-298.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998). Language discrimination by newborns: Towards an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 1-11.

Nazzi, T., & Jusczyk, P. W. (submitted). Discriminating languages from the same rhythmic class: Data from 5-month-old English-learners. .

Nespor, M. (1990). On the rhythm parameter in phonology. In I. M. Roca (Ed.), *Logical issues in language acquisition* (pp. 157-175). Dordrecht: Foris.

Nespor, M., Guasti, M. T., & Christophe, A. (1996). Selecting word order: the Rhythmic Activation Principle. In U. Kleinhenz (Ed.), *Interfaces in Phonology* (pp. 1-26). Berlin: Akademie Verlag.

Neville, H. J., Bavelier, D., Corina, D., Rauschecker, J., Karni, A., Lalwani, A., Braun, A., Clark, V., Jezzard, P., & Turner, R. (1998). Cerebral organization for language in deaf and hearing subjects: biological constraints and effects of experience. *Proc. Natl. Acad. Sci., 95*(February 1988), 922-929.

O'Leary, D. S., Andreasen, N. C., Hurtig, R. R., Hichiwa, R. D., Watkins, G. L., Ponto, L. L. B., Rogers, M., & Kirchner, P. T. (1996). A Positron Emission tomography study of binaurally and dichotically presented stimuli: effects of level of language and directed attention. *Brain and Language, 53*, 20-39.

Pallier, C., Christophe, A., & Mehler, J. (1997). Language-specific listening. *Trends in Cognitive Science, 1*(4), 129-132.

Pallier, C., Sebastian-Galles, N., Dupoux, E., Christophe, A., & Mehler, J. (1998). Perceptual adjustment to time-compressed speech: a cross-linguistic study. *Memory & Cognition, 26*, 844-851.

Paulesu, E., & Mehler, J. (1998). Right on in sign language. *Nature, 392*, 233-234.

Perani, D., Paulesu, E., Sebastian-Galles, N., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S., Fazio, F., & Mehler, J. (1998). The bilingual brain: Proficiency and age of acquisition of the second language. *Brain, 121*, 1841-1852.

Pike, K. L. (1945). *The intonation of American English*. Ann Arbor, Michigan: University of Michigan Press.

Prince, A., & Smolensky, P. (1993). *Optimality theory: constraint interaction in generative grammar* (TR-2). New Brunswick: Rutgers University.

Quinn, P. C., Eimas, P. D., & Rosenkrantz, S. L. (1993). Evidence for the representation of perceptually similar natural categories by 3-month old and 4-month old infants. *Perception, 22*, 463-475.

Ramus, F., Nespor, M., & Mehler, J. (in press). Correlates of linguistic rhythm in the speech signal. *Cognition*.

Reilly, J. S., Bates, E. A., & Marchman, V. A. (1998). Narrative Discourse in Children with Early Focal Brain Injury. *Brain & Language*, *61*, 335-375.

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

Segalowitz, S. J., & Chapman, J. S. (1980). Cerebral asymmetry for speech in neonates: A behavioral measure. *Brain and Language, 9*, 281-288.

Tinbergen, N. (1951). *The study of Instinct.* (Vol. Oxford University Press). Oxford.

Weber-Fox, C. M., & Neville, H. J. (1996). Maturational Constraints on Functional Specializations for Language Processing: ERP and Behavioral evidence in Bilingual Speakers. *Journal of Cognitive Neuroscience, 8*(3), 231-256.

Werker, J. F., & Polka, L. (1993). The ontogeny and developmental significance of language-specific phonetic perception. In B. de Boysson-Bardies, S. de Schonen, P. W. Jusczyk, P. McNeilage, & J. Morton (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 275-288). Dordrecht, Netherlands: Kluwer.

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7*, 49-63.

Woods, B. T., & Teuber, H.-L. (1978). Changing patterns of childhood aphasia. *Annals of Neurolog, 3*, 273-280.

Woods, M. T., & Carey, S. (1979). Language deficits after apparent clinical recovery from childhood aphasia. *Annals of Neurology, 3*, 273-280.