62 Acquisition of Languages: Infant and Adult Data

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ABSTRACT This chapter advocates a multidimensional approach to the issues raised by language acquisition. We bring to bear evidence from several sources–experimental investigations of infants, studies of bilingual infants and adults, and data from functional brain-imaging–to focus on the problem of early language learning. At bottom, we believe that our understanding of development and knowledge attainment requires the joint study of the initial state, the stable state, and the mechanisms that constrain the timetables of learning. And we are persuaded that such an approach must take into account data from many disciplines.

What advantage can a newborn infant draw from listening to speech? Possibly none, as was thought not so long ago (Mehler and Fox, 1985). But now we conjecture that the speech signal furnishes information about the structure of the mother tongue (see Christophe et al., 1997; Gleitman and Wanner, 1982; Mazuka, 1996; Mehler and Christophe, 1995). This position, dubbed the "phonological bootstrapping" hypothesis (Morgan and Demuth, 1996a), reflects an increasing tendency in language acquisition research (Morgan and Demuth, 1996b; Weissenborn and Höhle, 1999)–namely, that language acquisition starts very early and that a purely phonological analysis of the speech signal (a surface analysis) gives information about the grammatical structure of the language.

Phonological bootstrapping rests on the idea that language is a species-specific ability, the product of a "language organ" specific to human brains. Hardly new, this view has been advocated by psychologists, linguists, and neurologists since Gall (1835). Lenneberg (1967) initially provided much evidence for the biological foundations of language, evidence that has been corroborated by other research programs (for review, see Mehler and Dupoux, 1994; Pinker, 1994). Human brains appear to have specific neural structures, part of the species endowment, that mediate the grammatical systems of language. Noam Chomsky (1988) proposed conceiving of the "knowledge of language" that newborns bring to the task of acquiring a language in terms of principles and parameters–universal principles that are common to all human languages and parameters that elucidate the diversity of natural languages (together, then, principles and parameters constitute Universal Grammar). Parameters are set through experience with the language spoken in the environment (for a different opinion about how about species-specific abilities may be innately specified, see Elman et al., 1996).

In this chapter, we first present experimental results with infants to illustrate the phonological bootstrapping approach. We then examine how word forms can be learned. Finally, we discuss studies of the cortical representation of languages in bilingual adults, who, by being bilingual, exhibit the end result of a special (though frequent) language-learning case. The structure of this chapter illustrates an unconventional view of development. Given the task of presenting language acquisition during the first year of life, why do we include studies on the representation of languages in adult bilinguals? We do so in the belief that development is more than the study of change in developing organisms. To devise an adequate theory of how an initial capacity turns into the full-fledged adult capacity, we need a good description of both endpoints. In addition, considering both endpoints together while focusing on the problem of development is a good research strategy, one that has increased our understanding of language acquisition.

Phonological bootstrapping

In our previous chapter (Mehler and Christophe, 1995), we started from the fact that many babies are exposed to more than one language–languages that must be kept separate in order to avoid confusion. We reviewed a number of studies that illustrate such babies' ability to discriminate between languages. The picture that emerged was that, from birth onward, babies are able to distinguish their mother tongue from foreign languages (Bahrick and Pickens, 1988; Mehler et al., 1988); moreover, they show a preference for their mother tongue (Moon, Cooper, and Fifer, 1993). Both these facts hold when speech is low-pass–filtered, preserving only prosodic

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information (Dehaene-Lambertz and Houston, 1998; Mehler et al., 1988). In addition, after reanalyzing our data (from Mehler et al., 1988), we noticed a developmental trend between birth and 2 months of age: Whereas newborns discriminated between two foreign languages, 2-month-olds did not. More recent data confirm this developmental trend. Thus, Nazzi, Bertoncini, and Mehler (1998) showed that French newborns could discriminate filtered sentences in English and Japanese; and Christophe and Morton (1998) showed that, while English 2-month-olds do not react to a change from French to Japanese (using unfiltered sentences), they do discriminate between English and Japanese in the same experimental setting. A possible interpretation of this counterintuitive result is that, while newborns attempt to analyze every speech sample in detail, 2-month-olds have gained enough knowledge of their mother tongue to be able to filter out utterances from a foreign language as irrelevant. As a consequence, they do not react to a change from one foreign language to another. This takes place when the infant is about 2 months old, and thus marks one of the earliest reorganizations of the perceptual responses as a result of exposure to speech.

When Mehler and colleagues (1996) proposed a framework to explain babies' ability to discriminate languages, they began with two facts: first, that babies discriminate languages on the basis of prosodic properties and, second, that vowels are salient features for babies (see Bertoncini et al., 1988; Kuhl et al., 1992). They conjectured that babies construct a grid-like representation containing only vowels. Such a representation would facilitate the discrimination of the language pairs reported. Indeed, the pairs invariably involved *distant* languages. In addition, it predicts that infants should have most difficulty discriminating languages having similar prosodic/rhythmic properties. It is assumed that the vowel grid represents the languages of the world as clusters around discrete positions in the acoustic space.

Nazzi, Bertoncini, and Mehler (1998) began to test some predictions of this framework. First, they showed that French newborns fail to discriminate English and Dutch filtered sentences. English and Dutch share a number of prosodic properties (complex syllables, vowel reduction, similar word stress) and both are "stress-timed"; they should therefore receive similar grid-like representations. The authors also investigated the question of whether languages receiving similar grid representation would be grouped into one single category–a language family or class. To that end, they selected four languages falling into two language classes: Dutch and English (stress-timed), and Spanish and Italian (syllable-timed). They presented infants with a mixture of filtered sentences from two different languages. When habituated to sentences in Dutch and English, infants responded to a change in Spanish and Italian sentences, and vice versa. In contrast, when habituated to English and Spanish and tested with Dutch and Italian, infants failed to discriminate. (Note: All the possible interlanguage class combinations were used.) Infants reacted only if a change of language class had taken place (see figure 62.1). These experiments suggest that infants spontaneously classify languages into broad classes or rhythmic-prosodic families, as hypothesized.

So now we know that some languages are more similar than others, even for babies. How can we learn more about the metric underlying perceptual judgments? Two lines of research have allowed us to investigate the perceptual space. One of these exploits adaptation to time-compressed speech (artificially accelerated speech, which is about twice as fast as normal speech). Subjects are asked to listen to and comprehend compressed sentences. Comprehension is initially rather poor; but subjects habituate to compressed speech, and their performance improves after listening to a few sentences (Mehler et al., 1993). Dupoux and Green (1997) observed that adaptation resists speaker change, demonstrating that adaptation takes place at a relatively abstract level. However, Altmann and Young (1993) reported adaptation to compressed speech in sentences composed of nonwords, showing that lexical access is not necessary for adaptation. Similarly, Pallier and colleagues (1998) found that monolingual Spanish subjects listening to Spanish compressed sentences benefit from previous exposure to highly compressed Catalan, a language that they were unable to understand. The same pattern of results was observed when monolingual British subjects were exposed to highly compressed Dutch. Pallier and colleagues (1998) also reported that French-English bilinguals showed no transfer of adaptation from French to English, or vice-versa, again demonstrating that comprehension contributes, at best, very little to adaptation.

These results were interpreted in terms of the phonological (prosodic and rhythmical) similarity of the adapting and the target languages. Phonologically similar languages, such as Catalan and Spanish or English and Dutch, show transfer of adaptation from one member of the pair to the other; however, adaptation to French or English, two phonologically dissimilar languages, does not transfer from one to the other. Sebastian-Gallés, Dupoux, and Costa (1999) extended these findings by adapting Spanish subjects to Spanish, Italian, French, Greek, English, or Japanese sentences. Sebastian-Gallés and colleagues replicated and extended the findings by Pallier and co-workers; in particular, they observed that Greek, which shares rhythmic properties with Spanish

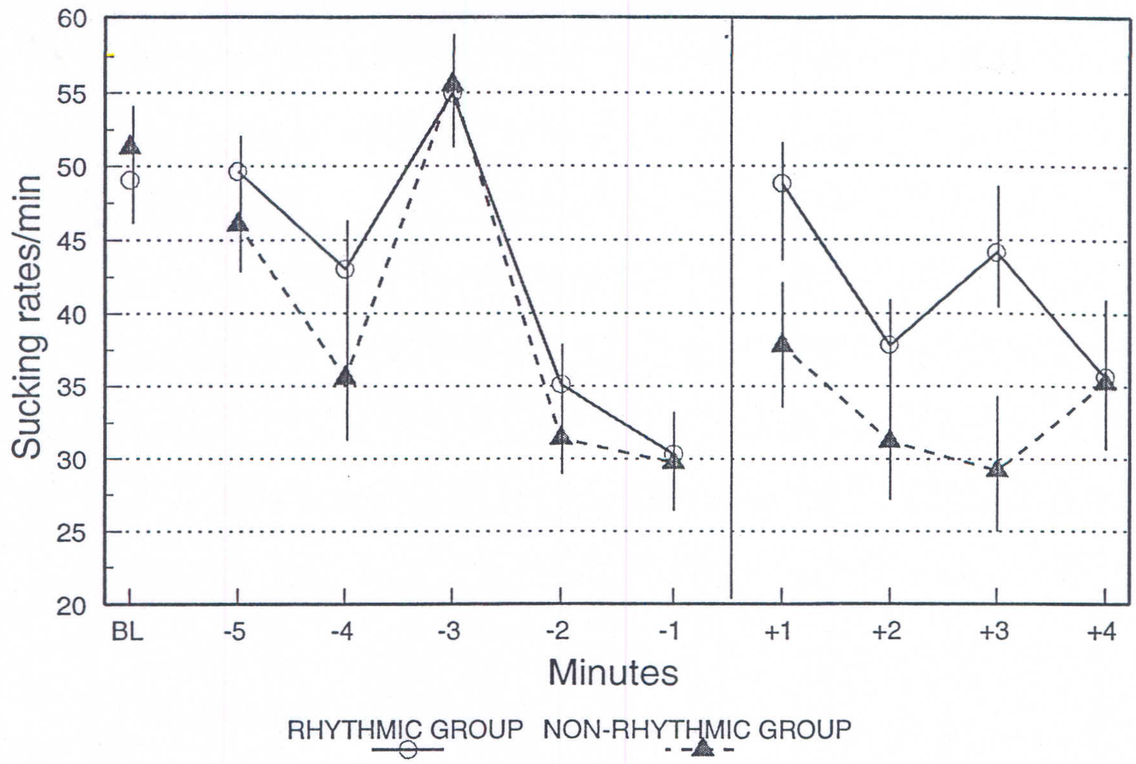

FIGURE 62.1 Results of a nonnutritive sucking experiment: Auditory stimulation is presented contingently upon babies' high-amplitude sucks on a blind dummy. After a baseline period without stimulation, babies hear sentences from one category until they reach a predefined habituation criterion. They are then switched to sentences from the second category. The graph displays sucking-rate averages for 32 French newborns for the baseline period, 5 minutes before the change in stimulation, and 4 minutes after the change. The rhythmic group was switched from a mixture of sentences taken from two stress-timed languages (Dutch and English) to a mixture of sentences from two syllable-timed languages (Spanish and Italian), or vice versa. The nonrhythmic group also changed languages, but in each phase of the experiment there were sentences from one stress-timed and one syllable-timed language (e.g., Spanish and English, then Italian and Dutch). Infants from the rhythmic group reacted significantly more to the change of stimulation than infants from the nonrhythmic group, indicating that only those in the rhythmic group were able to form a category with the habituation sentences and notice a change in category (syllable-timed vs. stress-timed). (Adapted from Nazzi, Bertoncini, and Mehler, 1998.)

but has little lexical overlap, is very efficient in promoting adaptation to Spanish. These authors concluded that the technique of time-compressed speech can serve as a tool to explore the grouping of languages into classes. Another technique being assessed as a tool to study the metric of natural languages is speech resynthesis–a procedure that makes it possible to selectively preserve some aspects of the original sentences, such as phonemes, phonotactics, rhythm, and intonation (see Ramus and Mehler, 1999). It is too early to relate these early categorizations of languages with the language classifications proposed by comparative linguists and biologists (see Cavalli-Sforza, 1991; Renfrew, 1994).

So far, we have seen that the languages of the world can be organized on a metric; that is, some languages are more distant than others. This metric could be discrete, like the one Miller and Nicely (1955) proposed for phonemes–a space structured by a finite number of dimensions (e.g., the parameters within the principles-and-parameters theory). Or it could be a continuous space, without structure, with as many dimensions as there are languages. Mehler and colleagues (1996) claimed that the first option should be correct because the metric of languages, the underlying structure, could aid in acquisition. The way a language sounds (i.e., its phonological information) would help infants to discover some properties of their native language and allow them to start the process of acquisition. This is a kind of phonological bootstrapping.

One recent proposal (Nespor, Guasti, and Christophe, 1996) illustrates how phonological information may bootstrap the acquisition of syntax. Languages vary as to the way words are organized in sentences. Either complements follow their heads, as in English or Italian (e.g., *He reads the book*, where *book* is the complement of *read*), or they precede their heads, as in Turkish or Japanese (e.g., *KitabI yazdim* [*The-book I-read*]). This structural property possesses a prosodic correlate: In head-initial languages like English, prominence falls at the end of phonological phrases (small prosodic units, e.g., *the big book*), but in head-final languages like Turkish, prominence falls at the beginning of phonological phrases. Therefore, if babies can hear whether prominence falls at the beginning or end of phonological phrases, they can decipher their language's word order. Infants could understand some structural aspects before they learn words (see Mazuka, 1996, for a discussion). They could use their knowledge of the typical order of words in their mother tongue to guide the acquisition of word meanings (e.g., see Gleitman, 1990).

If babies are to use prosodic information to determine the word order of their language, they should first be able to perceive the prosodic correlates of word order. In order to test the plausibility of this hypothesis, Christophe and colleagues (1999) compared two languages that differ on the head-direction parameter, but have otherwise similar prosodic properties: French and Turkish. Both languages have word-final stress, fairly simple syllabic structure through resyllabification, and no vowel reduction. Matched sentences in the two languages were constructed such that they had the same number of syllables, and their word boundaries and phonological phrase boundaries fell in the same places. Only prominence within phonological phrases distinguished these sentences. They were read naturally by native speakers of French and Turkish. And, in order to eliminate phonemic information while preserving prosodic information, the sentences were resynthesized so that all vowels were mapped to schwa and consonants by manner of articulation (stops, fricatives, liquids, etc.). The prosody of the original sentences was copied onto the resynthesized sentences. An initial experiment showed that 2-month-old French babies were able to distinguish between these two sets of sentences (see also Guasti et al., 1999). This result suggests that babies are able to perceive the prosodic correlate of word order well before the end of the first year of life (although additional control experiments are needed to rule out alternative explanations). As they stand, the findings support the notion that babies determine the word order of their language before the end of the first year of life–about the time that lexical and syntactic acquisition begins.

This proposal is an example of how purely phonological information (in that case, prosodic information) directly gives information about syntax. Languages differ not only in syntax, but in their phonological properties as well; and babies may learn about these properties of their mother tongue early in life. (The alternative is that children learn the phonology of a language when they learn its lexicon, after age 1). In fact, recent experiments have shown that the adult speech processing system is shaped by the phonological properties of the native language (e.g., Cutler and Otake, 1994; Otake et al., 1996; see Pallier, Christophe, and Mehler, 1997, for a review). For instance, Dupoux and his colleagues examined Spanish and French adult native speakers' processing of stress information (stress is contrastive in Spanish: *BEbe* and *beBE* are different words, meaning "baby" and "drink," respectively; in French stress is uniformly word-final). They used an ABX paradigm where subjects listened to triplets of pseudowords and had to decide whether the third one was like the first or like the second one (Dupoux et al., 1997). They observed that French native speakers were almost unable to make the correct decision when stress was the relevant factor (e.g., *VAsuma, vaSUma, VAsuma*, correct answer first item), whereas Spanish speakers found it as straightforward to monitor for stress as to monitor for phonetic content. In addition, Spanish speakers found it very hard to base their decision on phonemes when stress was an irrelevant factor (e.g., *VAsuma, faSUma, vaSUma*, correct answer first item), whereas French speakers happily ignored the stress information. In another set of experiments, Dupoux and colleagues investigated the perception of consonant clusters and vowel length in French and Japanese speakers (Dupoux et al., 1999). In French, consonant clusters are allowed but vowel length is irrelevant, while in Japanese, consonant clusters are not allowed and vowel length is relevant. They observed that Japanese speakers were at chance level in an ABX task when the presence of a consonant cluster was the relevant variable (e.g., *ebzo, ebuzo, ebuzo*, correct answer second item), whereas they performed very well when they had to base their decision on vowel length (e.g., *ebuzo, ebuuzo, ebuzo*, correct answer first item). In contrast, French speakers showed exactly the reverse pattern of performance (see figure 62.2).

All these results suggest that adult speakers of a language listen to speech through the filter of their own phonology. Presumably, they represent all speech sounds with a sublexical representation that is most adequate for their mother tongue, but inadequate for foreign languages. How and when do babies learn about such phonological aspects of their mother tongue? Although we still lack experimental results on this topic, we conjecture that babies must stabilize the correct sublexical representation for their mother tongue sometime during the first year of life. Thus, when they start acquiring a lexicon toward the end of their first year, they may directly establish lexical representations in a format that is most suitable to their mother tongue. Consistent with this view, evidence is emerging that the representations in adults' auditory input lexicon depend on the phonological properties of the native language (Pallier et al., 1999).

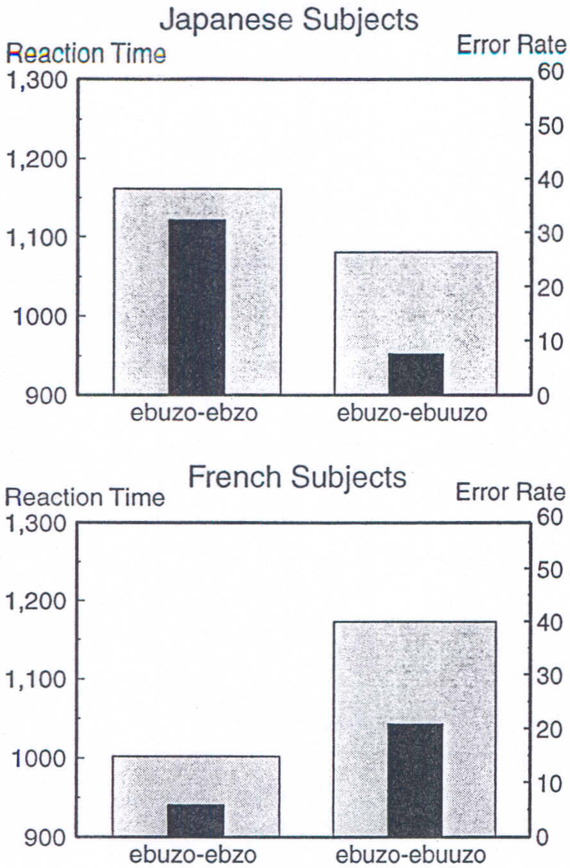

FIGURE 62.2 Reaction times (in gray) and error rates (in black) to ABX judgments in French and Japanese subjects on a vowel length contrast and on an epenthesis contrast. (Adapted from Dupoux et al., 1999.)

Here we have discussed one particular kind of phonological bootstrapping, whereby the way a language sounds gives information as to its abstract structure (such as the head-direction parameter, or the kind of sublexical representation it uses). Phonological information may help bootstrap acquisition in other ways (Morgan and Demuth, 1996a): For instance, prosodic boundary information may help parse a sentence (e.g., Morgan, 1986); prosodic and distributional information may help reveal word boundaries (e.g., Christophe and Dupoux, 1996; Christophe et al., 1997); and phonological information may help to categorize words (see Morgan, Shi, and Allopenna, 1996). This is not to imply that everything about language can be learned through a purely phonological analysis of the speech signal during the first year of life and before anything else has been learned. Of course this is not the case. For instance, although we argued that some syntactic properties may be cued by prosodic correlates (e.g., the head-direction parameter), we do not claim that prosody contains traces for *all* syntactic properties. But if the child can discover only a few basic syntactic properties from such traces, learning is made easier. The number of possible grammars diminishes by half with each parameter that is set (for binary parameters). As a consequence, the first parameter that is set eliminates the largest number of candidate grammars (see Fodor, 1998; Gibson and Wexler, 1994; Tesar and Smolensky, 1997, for discussions about learnability). In other words, a purely phonological analysis may *bootstrap* the acquisition process but not solve it entirely. Fernald (Fernald and McRoberts, 1996) also discussed the potential help of prosody in bootstrapping syntactic acquisition: She criticized this approach on the grounds that the proportion of syntactic boundaries reliably cued by prosodic cues (pauses, lengthening, etc.) is not high. Some syntactic boundaries are not marked and some cues appear in inadequate positions. If so, children may often think that a syntactic boundary is present when none is and posit erroneous grammars. This argument holds only if one assumes that children use prosodic boundaries to parse every sentence they hear. Infants' brains may instead keep statistical tabs established on the basis of prosody and use such information to learn something about their language. For instance, they may tally the most frequent syllables at prosodic edges, in which case they find the function words and morphemes of their language at the top of the list. In that view, it does not matter very much if prosodic boundaries do not correlate perfectly with syntactic boundaries.

Learning words

Learning the syntax and phonology of their native language is not all babies have to do to acquire a functioning language. They also have to learn the lexicon–an arbitrary collection of word forms and their associated meanings (word forms respect the phonology of the language, but there is no systematic relationship between form and meaning). Experimental work shows that babies start to know the meaning of a few words at about 1 year of age (Oviatt, 1980; Thomas et al., 1981), and this is consistent with parental report. Mehler, Dupoux, and Segui (1990) argued that infants must be able to segment and store word forms in an appropriate language-specific representation before the end of the first year of life in order to be ready for the difficult task of linking word forms to their meaning (Gleitman and Gleitman, 1997). Recent experiments by Peter Jusczyk and colleagues supported this view by showing that babies are able to extract word forms from the speech stream and remember them by about 8 months of age. Jusczyk and Aslin (1995) showed that 7.5-month-olds attended less to new words than to "familiar" words–i.e., isolated monosyllabic words with which they had been familiarized in the context of whole sentences. This result was later replicated with multisyllabic words, indicating that babies of this age have at least some capacity to extract word-like units from continuous speech (Jusczyk, 1996). These word forms are not forgotten immediately afterwards. When 8-month-olds were repeatedly exposed to recorded stories at home then brought into the lab a week later, they exhibited a listening preference to words that frequently occurred in these stories (Jusczyk and Hohne, 1997).

How do babies extract word forms from the speech stream? This area of research has exploded since our last version of this chapter, and we now have a reasonably good view of what babies might do. Babies may exploit distributional regularities (i.e., segments belonging to a word tend to cohere). Brent and Cartwright (1996) showed that an algorithm exploiting these cues could recover a significant number of words from unsegmented input. In addition, Morgan (1994) demonstrated that 8-month-old babies exploited distributional regularity to package unsegmented strings of syllables (see also Saffran, Aslin, and Newport, 1996). Babies may also exploit the phonotactic regularities of the language, such as the fact that some strings of segments occur only at the beginning or at the end of words. Babies may learn about these regularities by examining utterance boundaries, then use these regularities to find word boundaries (Brent and Cartwright, 1996; Cairns et al., 1997). Interestingly, Friederici and Wessels (1993) showed that at 9 months, babies are already sensitive to the phonotactic regularities of their native language (see also Jusczyk, Cutler, and Redanz, 1993; Jusczyk, Luce, and Charles-Luce, 1994).

Next, babies may rely on their knowledge of the typical word shapes of their language. Anne Cutler and her colleagues extensively explored a well-known example of such a strategy in English. Cutler's metrical segmentation strategy relies on the fact that English content words predominantly start with a strong syllable (containing a full vowel, as opposed to a weak syllable containing a reduced vowel). Adult English-speaking listeners make use of this regularity when listening to faint speech or when locating words in nonsense syllable strings (e.g., Cutler and Butterfield, 1992; McQueen, Norris, and Cutler, 1994). Importantly, 9-month-old American babies prefer to listen to lists of strong-weak words (bisyllabic words in which the first syllable is strong and the second weak) than to lists of weak-strong words (Jusczyk et al., 1993). In addition, Peter Jusczyk and his colleagues showed, in a recent series of experiments, that babies of about 8 months find it easier to segment strong-weak (SW) words than weak-strong (WS) words from passages (Newsome and Jusczyk, 1995).

Finally, babies may rely on prosodic cues to perform an initial segmentation of continuous speech. Prosodic units roughly corresponding to phonological phrases (small units containing one or two content words plus some grammatical words or morphemes) were shown to be available to adult listeners (de Pijper and Sanderman, 1994), and presumably to babies as well (Christophe et al., 1994; Gerken, Jusczyk, and Mandel, 1994; see also Morgan, 1996; Fisher and Tokura, 1996, for evidence that prosodic boundary cues have robust acoustic correlates in infant-directed speech). These prosodic units would not allow babies to isolate every word; however, they would provide a first segmentation of the speech stream and restrict the domain of operation of other strategies (e.g., distributional regularities). In addition, prosodic units possess the interesting property that they derive from syntactic constituents (in a nonisomorphic fashion; see Nespor and Vogel, 1986); as a consequence, function words and morphemes tend to occur at prosodic edges. Therefore, infants may keep track of frequent syllables at prosodic edges, and the most frequent will correspond to the function words and morphemes in their language. Actually, LouAnn Gerken and her colleagues showed that 11-month-old American babies reacted to the replacement of function words by nonwords, indicating that they already knew at least some of the English function words (Gerken, 1996). Once babies have identified the function words of their native language, they may "strip" syllables homophonous to function words from the beginning and end of prosodic units; the remainder can then be treated as one or several content words.

This area of research illustrates particularly well the advantages of studying adults and babies simultaneously. For instance, the fact that English speakers rely on the predominant word pattern of English to perform lexical segmentation was first shown for adult subjects; this result was then extended to babies between 8 and 12 months of age. Reciprocally, the use of prosody to hypothesize word or syntactic boundaries was first advocated to solve the acquisition problem, and is now being fruitfully studied in adults (e.g., Warren et al., 1995).

The bilingual brain

We have argued that the speech signal provides fairly useful hints to isolate some basic properties of one's maternal language. There is, however, a situation that presents the infant with incompatible evidence; that is, sometimes two languages are systematically presented at the same time in the environment. But this apparently insurmountable problem is readily solved by every child raised in a multilingual society–no important delay in language acquisition has ever been documented. We have to provide a model of language acquisition that can account for that.

Bosch and Sebastian-Gallés (1997) have shown that at 4 months bilingual Spanish/Catalan babies already behave differently than do monolingual controls of either language. These investigators showed that monolingual babies orient faster to their mother tongue (Spanish for half of the babies and Catalan for the other half) than to English. In contrast, bilingual babies orient to Spanish or Catalan significantly more slowly than to English. In more recent and still unpublished work, these authors show that the bilingual infants can discriminate between Spanish and Catalan, indicating that confusion cannot be adduced to explain the above results. Needing to keep the languages separate, bilingual infants might be performing more fine-grained analyses of both Spanish and Catalan, and hence need more processing time.

Does the bilingual baby become equally competent in both languages? To answer this question, we have to study adult bilinguals. Pallier, Bosch, and Sebastian-Gallés (1997a) studied Spanish/Catalan bilinguals who learned to speak Catalan and Spanish before the age of 4 (although one language was always dominant–the one spoken by both parents). Whereas Spanish has only one /e/ vowel, Catalan has two, an open and a closed /e/. Pallier and colleagues showed that the Spanish-dominant speakers could not correctly perceive the Catalan vocalic contrast, even though they had had massive exposure to that language and spoke it fluently. Had these subjects been exposed to both languages in the crib, would they have learned both vowel systems? Behavioral studies are not yet readily available.

In the remainder of this section, we will review what brain-imaging techniques can tell us about language representation in bilingual adults. Mazoyer and colleagues (1993) explored brain activity in monolingual adults who were listening to stories in their maternal tongue (French) or in an unknown foreign language (Tamil). Listening to French stories activated a large left hemisphere network including parts of the prefrontal cortex and the temporal lobes–a result that is congruent with the standard teachings of neuropsychology.[1] In contrast, the activation for Tamil was restricted to the midtemporal areas in both the left and right hemispheres. Was the left hemisphere of the French Ss activated by French because it was the participants' mother tongue or because French, in contrast to Tamil, was a language they understood? Perani and colleagues (1996) investigated native Italians with moderate-to-good English comprehension. When Italians were listening to Italian, they exhibited the same pattern of activation as that reported in the Mazoyer study. Italians listening to and understanding English displayed a weak symmetrical right-hemisphere and left-hemisphere activation. Surprisingly, they displayed a similar activation when listening to stories in Japanese, a language they did not understand.[2] Comparing the cortical activation to English and Japanese ought to have uncovered the cortical areas dedicated to processing the words, syntax, and semantics of English. Figure 62.3 illustrates the fact that our expectation was not fulfilled.

How can we explain this failure? It seems unlikely that natural languages should yield comparable activation regardless of comprehension. An alternative account is that the native language yields the same cortical structures in every volunteer while a second language "shows greater inter-individual variability and therefore fails to stand out when averaged across subjects." Dehaene and colleagues (1997) used fMRI to explore this possible explanation. They examined eight French volunteers who had a fair understanding of English comparable in proficiency to the bilinguals tested by Perani and co-workers. The French volunteers listened to French or English stories and backward speech in alternation. When listening to French, their mother tongue, they all showed more activity in and around the left superior temporal sulcus. But when they listened to English, left and right cortical activation was highly variable among subjects (see figure 62.4). This result may reflect the fact that a second language may be learned in a number of different ways (e.g., through explicit tuition or more naturally), and hence the end result may vary from one individual to the next. To assess this, we need to examine the cortical representation of the second language when it was learned in a natural setting during childhood.

Perani and colleagues (1997) tried to explore these issues by testing two groups of highly proficient bilinguals. The first were Spanish/Catalan bilinguals who had acquired their second language between ages 2 and 4 and appeared to be equally proficient in both of their languages (but see Pallier, Bosch, and Sebastian-Gallés, 1997a, who tested the same population of subjects). The second were Italians who had learned English after the age of 10 and had attained excellent performance. The main finding of this PET study was that the cortical representations of the two languages were very similar (for both groups of high-proficiency bilinguals), and significantly different from that in low-proficiency bilinguals. This study suggests that proficiency is more important than age of acquisition as a determinant of cortical representation of the second language, at least in bilinguals who speak languages that are historically, lexically, and syntactically reasonably close (even though there are phonological differences). All these studies investigated

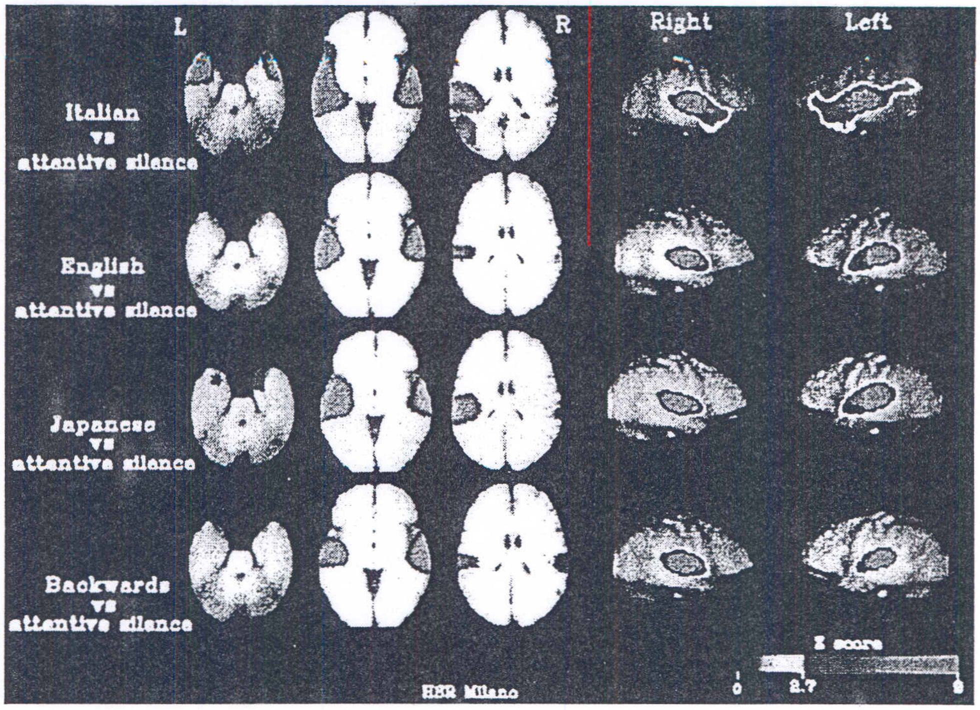

FIGURE 62.3 Patterns of activation in a PET study measuring the activity in Italian speakers' brains while listening to Italian (mother tongue), English (second language), Japanese (unknown language), and backward Japanese (not a possible human language). There was a significant activation difference between Italian and English. In contrast, English and Japanese did not differ significantly. Japanese differed significantly from backward Japanese. (Adapted from Perani et al., 1996.)

the cortical activation while *listening* to speech. What happens for speech *production*?

Kim and colleagues (1997) investigated a kind of speech production situation: They used fMRI with bilingual volunteers who were silently speaking in either of their languages. They tested bilingual volunteers who mastered their second language either early or late in life (the languages involved in the study were highly varied). They found that the first and second languages have overlapping representation in Broca's area in early learners whereas these representations are segregated in late learners. In contrast, both languages overlap over Wernicke's area regardless of age of acquisition. However, only age of acquisition and not proficiency was controlled; thus it is difficult to evaluate their separate contribution. As Perani and colleagues have indicated, there is a negative correlation between age of acquisition and proficiency (Johnson and Newport, 1989).

How can we harmonize the picture we get from the brain imaging studies with behavioral results? Even with very proficient bilinguals, it has been shown that the languages are not equivalent: People behave as natives in their dominant language and do not perform perfectly well in the other language. This has been shown for phonetic perception (Pallier, Bosch, and Sebastian-Gallés, 1997a), sublexical representations (Cutler et al., 1989; 1992), grammaticality judgments (Weber-Fox and Neville, 1996), and speech production (Flege, Munro, and MacKay, 1995). Possibly, the fact that the cortical representations for the first and second languages tend to span overlapping areas with increased proficiency cannot be taken to mean equivalent competence. As Perani and colleagues state:

> A possible interpretation of what brain imaging is telling us is that in the case of low proficiency individuals, the brain is recruiting multiple, and variable, brain regions, to handle as far as possible the dimensions of the second language, which are different from the first language. As proficiency increases, the highly proficient bilinguals use the same neural machinery to deal with the first and the second languages. However, this anatomical overlap cannot exclude that this brain network is using the linguistic structures of the first language to assimilate less than perfectly the dimensions of the second language.

Another inconsistency will have to be explained in future work. We know from several studies (e.g., Cohen et al., 1997; Kaas, 1995; Rauschecker, 1997; Sadato et al., 1996) that changing the nature and distribution of sensory input can result in important modifications of the cortical maps, even in adult organisms. However, people do not reach native performance in a second language, despite massive exposure, training, and motivation. Can we reconcile cortical plasticity with behavioral rigidity?

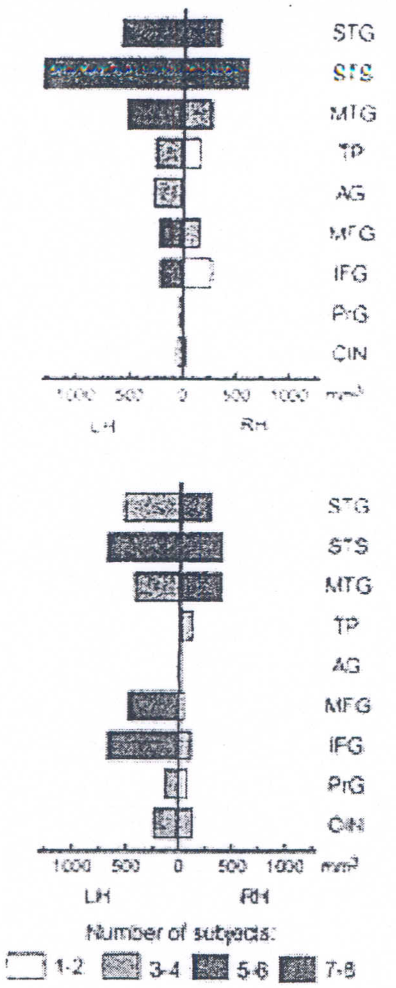

FIGURE 62.4 Intersubject variability in the cortical representation of language is greater for the second than for the first language. Each bar represents an anatomical region of interest (left and right hemisphere). Its length represents the average active volume (in square millimeters) in that region. Its color reflects the number of subjects in which that region was active. (Adapted from Dehaene et al., 1997.)

Yet another area in great need of more research is the functional significance of activation maps in general. Consider the work by Neville and her colleagues on the representation of American Sign Language (ASL) in deaf and hearing native signers. These authors carried out an fMRI study and showed that ASL is bilaterally represented in both populations while written English is basically represented in the left hemisphere of the hearing signers (who were also native speakers of English). Hickok, Bellugi, and Klima (1996) studied 23 native speakers of ASL with unilateral brain lesions and found clear and convincing evidence for a left-hemispheric dominance, much like the one found in speakers of natural languages. This leaves us in a dilemma: Either we assert that it is not easy to draw functional conclusions from activation maps, and/or we have to posit that ASL is not a natural language.

Mapping the higher cognitive functions to neural networks is an evolving skill. In the near future, we expect to witness a trend toward a more exhaustive study of a given function in a single subject. For instance, each volunteer could be tested several times to investigate in detail how language competence is organized and represented in his/her cortex. This should help us to elucidate several of the seemingly paradoxical findings we reported above. However things evolve, it is clear that when we understand these issues in greater depth, we will be able to make gigantic leaps in our understanding of development.

Conclusion

We have presented data drawn from experimental psychology, infant psychology, and brain-imaging to propose another way of addressing the study of development–this, to illustrate an approach to the study of development now gaining in support. By bringing together some of the areas that jointly clarify how the human mind gains access to language, logic, mathematics, and other such recursive systems, we can begin to answer several fundamental questions: (1) Why is the acquisition of some capacities possible for human brains and not for the brains of other higher vertebrates? (2) Are there skills that can be acquired more naturally and with a better outcome before a certain age? (3) Does the acquisition of some skill facilitate the acquisition of similar skills in older organisms–those who would normally show little disposition to learn "from scratch"? The need to answer such questions is the essence of many developmental research programs. The fact that questions like these are being has implications for the cognitive psychologist and cognitive neuroscience. Cognitive psychologists are becoming increasingly aware that they must conceive of development as a critical aspect of cognitive neuroscience. If, for instance, there are time schedules to naturally learn certain skills, the joint study of the time course of development and the concurrent maturation of neural structures may tell us which neural structures are responsible for the acquisition of which capacities. Coupled with brain-imaging and neuropsychological data, these facts may help us to understand better the mapping between neural structure and cognitive function. One may call such a study the "neuropsychology of the normal."

In concluding, we dispute the notion that the acquisition of mental abilities can be sufficiently studied by looking only at growing children. We suggest that to understand the mechanisms responsible for change, one must first specify the normal envelope of stable states and the species-specific endowment; then we can go on to develop a theory of acquisition that accounts for the mapping from the initial to the stable state. Many different disciplines will have to participate in achieving this goal. Neuroscience has made many discoveries that are essential to the understanding of development; in particular, brain-imaging studies may bring in a new perspective to the research of growth and development. Thus, rather than making the study of development an autonomous part of cognition, we conceive of it as a unique source of information that should be an integral component of cognitive psychology.

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NOTES

1. There are some areas–e.g., the anterior poles of the temporal lobes and Brodmann 8–that had not often been related to language processing by classical neuropsychology.
2. Interestingly, the left inferior frontal gyrus, the left midtemporal gyrus, and the inferior left parietal lobule were more active when subjects were listening to Japanese compared to backward Japanese. These activations could mirror the subjects' attempt to store the input as meaningless phonological information in auditory short-term memory (see Paulesu, Frith, and Frackowiak, 1993). Perani and colleagues observed that the left middle temporal gyrus activation appeared only when subjects were listening to speech, regardless of whether they understood the stories, but not when listening to backward speech, an unnatural stimulus. The authors suggest that the left middle temporal gyrus is highly attuned to the processing of the sound patterns of any natural language.

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