59 Biological Foundations of Language Acquisition: Evidence from Bilingualism

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ABSTRACT This chapter presents a comprehensive view of language acquisition based on the notion that humans have mechanisms that respond specifically to speech signals. Some speech signals trigger statistical computations while others trigger rule-like processes. We present evidence that human brains are tuned to speech signals at birth. Next, we show that infants extract statistical information from speech signals, but also that they extract structural regularities that cannot be solely due to the statistical information contained in the signal.

We present results from a large typological study that includes data from many different languages. The outcome supports the view that languages can be sorted into classes. Properties of those classes may bias children toward the postulation of some linguistic structures rather than other possible structures that go with languages in other classes.

Arguing in favor of the study of language acquisition using realistic scenarios, we review data from infants acquiring two languages at once. We base our presentation on a large-scale project comparing the acquisition of two related languages, Spanish and Catalan, and two distant languages, Spanish and Basque. We conclude with a review of studies of adults who ought to have been bilingual but have forgotten their first language. These adults are undistinguishable from native speakers of their language of adoption.

This chapter attempts to establish how the brain of humans is endowed with specialized processes that respond to properties of signals with specialized computation and biases that are essential to the progress of language acquisition.

Humans acquire the grammatical systems underlying language in a smooth and effortless fashion if neurological disorders do not intervene to upset the language learning processes. Chomsky (1967) used this straightforward evidence as a cornerstone of his linguistic theory, and a number of psycholinguists have included it in their proposals about the psychology of language (see Mehler, 1994; Pinker, 1994). (It should be noted that others do not; see Tomasello, 2000.) In this chapter, we attempt to explore the notion that speech, the usual source for learning a language, contains specific cues that trigger biases and special kinds of computations.

There is evidence that even in the initial state, speech activates specialized brain regions homologous to those that mediate language in adulthood. We take those observations as an indication of the existence of specific mechanisms for acquiring language. Just after birth, infants start learning the language they are exposed to out of the thousands of languages currently spoken in the world. How does such learning happen? We claim that cues in the speech signal trigger specific computations. In particular, we present evidence that humans are excellent statistical machines and excellent at deriving rule-like generalizations, and that the computation in which they engage depends on the cues delivered by the stimulus configuration. Next we show that despite the variability of natural languages, there is a reliable correlation between some abstract grammatical properties and the acoustical properties of the utterances of a language. This evidence supports the best-developed conjecture as to how grammar might be learned, namely, parameter-setting theory (see Chomsky, 1988). However, such an approach must also be considered in a far from exceptional language learning setting: one in which more than one language is present. Although most theoreticians tacitly assume that languages are learned in a monolingual environment, bilingualism is widespread. How does the brain/mind respond to such a situation? We present data from studies in very young infants who are exposed to two languages while still in the crib. We also review how bilingualism affects the neural representation of the first- and second-acquired languages. In particular, we present data from individuals who lost their first-acquired language in favor of a second language acquired relatively late. We conclude that despite the large number of languages and structures, the cultural specificities of bilingual acquisition, and the personal histories of the language learner, the mind's robust language acquisition device maintains its capacity to master the native language.

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Theoretical perspectives on language acquisition

To understand the biological foundations of language, it is necessary to focus both on the species-specific disposition to acquire grammar and on the different types of mechanisms that guide acquisition despite the huge surface diversity of natural languages. Indeed, there are a number of suggestions that language acquisition and language use rely on more than one single kind of computation (see Marcus et al., 1999; Pinker, 1994; Peña et al., 2002).

Evidence for Signal-Driven Computations Different investigators have shown that at least two mechanisms play an active role in language acquisition, namely, the extraction of statistical regularities in the input and the ability of the learner to hypothesize rules to characterize structural regularities. Saffran, Aslin, and Newport (1996) have stressed that statistical information is essential for lexical segmentation, and Marcus and colleagues (1999) have argued that infants use algebraic-like computations to discover structures in speech. Saffran, Aslin, and Newport (1996) have shown that 8-month-olds parse a continuous, monotonous speech stream into constituent "words" on the basis of conditional probabilities. That is, infants perceive dips in transition probability (TP) between syllables as signaling "word" boundaries. However, 7-month-olds also use algebraic-like rules to establish the structural regularities of the utterances generated by a very simple grammar (see Marcus et al., 1999). The stimuli Saffran and colleagues used are monotonous, continuous streams of syllables of equal length and intensity. In contrast, Marcus and colleagues used lists of three-syllable items separated by silence.

Peña and colleagues (2002) proposed that specific signals received during language acquisition trigger special kinds of computations that may affect syntactic acquisition even in prelexical infants. They suggested that statistical and rule-like computations play an important role in language acquisition. They went further to explore the conditions that might cause the mind to rely mainly on statistical computations or to project rule-like conjectures. They familiarized some participants to continuous, meaningless, monotonous streams of syllables and other participants to the same stream after subliminal silent gaps were added after each "word." The syllables in the stream formed three trisyllabic words; the first syllable of each word predicted the third syllable. The stream can be described as having three AxC families, where x is a variable syllable used to generate three words per family. Words had a transition probability dip after the last syllable. Participants heard the continuous stream for 14 minutes and were tested afterwards. Although they could recognize the "words" they heard during familiarization, they did not accept rule-based words or Ax*C items, where x* denotes a syllable that occurred during familiarization but never between A and C. Thus, the authors concluded that participants had only computed transitional probabilities. However, when participants were familiarized with the stream containing silent subthreshold gaps, they accepted the rule-based words as familiar, suggesting that they had generalized to a rule-like conjecture, such as "if A then C, with a syllable between them." The inclusion of a minimal signal is thus sufficient to toggle the nature of participants' computations from statistical to rule-based. Trebling the duration of familiarization to the continuous stream to 30 minutes was insufficient for participants to extract the structural regularities present in the stream. However, reducing exposure to the stream with gaps to only 2 minutes was enough for participants to judge rule-like words as being familiar. Peña and colleagues hypothesized that when signals are unsegmented, statistics guides learning, whereas conjectures are automatically projected when minimal cues to segmentation are present.

To what extent are the human computational abilities during language acquisition signal-driven? This is a basic question whose answer might well clarify what the infant acquires during the first weeks of exposure to language. It is well known that infants pay attention to ambient language, and learn a great deal about speech from passive exposure to the signals in their surroundings. We know much less about how the gains made during the first few weeks may bias or guide the acquisition of the abstract properties of the surrounding language. We propose that just as gaps can drive computations in adults, so can some of the prosodic properties of speech drive computations in the infant.

Separating Languages: The Discovery of the Existence of Different Sound Systems As we stated in our opening comments, humans deploy their species-specific linguistic endowment to learn the properties of the surrounding language out of the thousands of existing languages to which they could be exposed. Psychologists often conjecture that associative learning underlies this acquisition. However, as argued in Chomsky's seminal writings, it seems unlikely that such a mechanism alone could account for language acquisition. We propose that the specific properties of the signal might guide the learning of (1) grammar, by giving cues to abstract properties, or (2) lexical properties, by computing statistical dependencies. This proposal is an extension of the prosodic bootstrapping hypothesis originally proposed by Morgan, Meier, and Newport (1987).

A prerequisite to language acquisition is the ability to distinguish linguistic from nonlinguistic signals (Colombo and Bundy, 1983) and to establish whether the input data represent one or more languages. If infants were unable to distinguish two languages to which they are exposed, they would be highly confused. Given that there is no evidence that early bilingual exposure causes a delay in language acquisition, we infer that bilingual infants must have ways to adjust their computations to each one of the input languages. How long does the bilingual infant take to acquire separate files for the languages in the surrounding environment? Some investigations of language production propose that infants do not differentiate the two languages present in the environment before their third year of life (Volterra and Taeschner, 1978; Redlinger and Park, 1980; Vihman, 1985; Genesee, 1989). However, neonates display behaviors that suggest that they begin to respond differently to some language pairs as early as they have been tested. Thus, procedures are needed to evaluate the linguistic representations of infants much earlier than their first word productions.

One way to explore this issue is to present infants with two languages, one for habituation and the other as a test. A large number of experiments have established that newborns discriminate some language pairs but fail to discriminate others. For instance, they distinguish Spanish versus English and English versus Japanese, but fail to distinguish Dutch versus English and Spanish versus Italian. In brief, as Mehler and colleagues (1988), Nazzi, Bertoncini, and Mehler (1998), and Ramus, Nespor, and Mehler (1999) have claimed, neonates and very young infants (less than 2 months old) discriminate languages if and only if the languages belong to different rhythmic classes, regardless of whether one of the languages is the one in their surroundings (see Christophe, 1998).

Phonologists such as Pike (1945), Abercrombie (1967), and Ladefoged (1975) were among the first to claim that languages differ in rhythm. Recently, Ramus, Nespor, and Mehler (1999) proposed that language rhythms can be described in terms of the patterns of alternation of vocalic and consonantal space (see Mehler and Christophe, 2000). This method of capturing language rhythms is also implicit in the work of some psycholinguists that explores cross-linguistic speech segmentation phenomena (Mehler et al., 1981; Cutler et al., 1983; Sebastián-Gallés et al., 1992; Otake et al., 1993).

According to the measures of Ramus, Nespor, and Mehler (1999), languages such as English, Dutch, or Polish, all supposedly stress-timed, cluster together. Spanish, Italian, and French, all supposedly syllable-timed, also cluster together. Japanese, a so-called mora-timed language, stands by itself, possibly because of the scarcity of languages included in the original measures.[1] The ability of newborns to discriminate among languages appears to depend on the ability to distinguish between languages belonging to these different rhythmic groups.

Subsequent work has added several unrelated languages to those plotted in the work of Ramus and colleagues (figure 59.1). It now appears that the languages that cluster with Japanese in the right part of figure 59.1, besides being mora-timed, tend to be complement-head (C-H) and/or agglutinative languages[2] or languages that have a relatively free word order. Indeed, the diagonal line in figure 59.1 divides languages into two groups, those that are head-complement (H-C), that is, English, Dutch, Polish, French, Spanish, Catalan, and Italian, and those that are mostly complement-

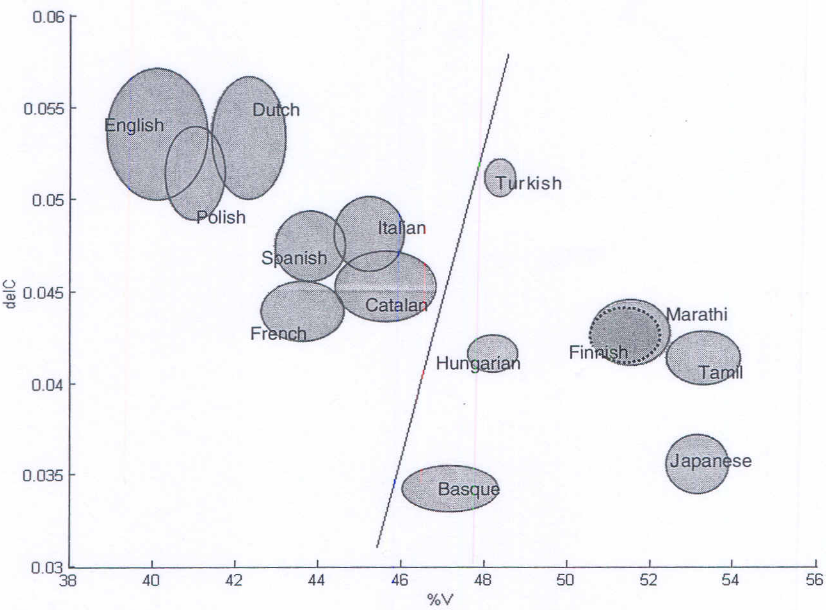

FIGURE 59.1 Fourteen languages plotted in the %V versus delC space first proposed by Ramus (1999, p. 150). All Romance languages and all Germanic languages (as well as Polish) tend to have low %V. We also present a selection of languages having higher values of %V. The diagonal line separates the languages into two groups. On the left are head-complement languages; the ones on the right tend to be complement-head languages.

head, that is, Basque, Hungarian, Turkish, Finnish, Japanese, Tamil, and Marathi. (It should be noted that Dutch and Hungarian are in fact "mixed" languages, because some phrases have a C-H order while others have H-C. However, Dutch is predominantly H-C, while Hungarian is mostly C-H.

A number of scientists have argued that prosodic bootstrapping is essential for the acquisition of abstract properties of grammars. Nespor, Guasti, and Christophe (1996), Christophe and Dupoux (1996), and Aslin and colleagues (1996) give specific examples to illustrate how prosodic bootstrapping might actually work. Nespor and colleagues (1996) argue that the correlation between the prominence of the phonological phrase (PP),[3] that is, its main stress and the value of the H-C parameter (Nespor and Vogel, 1986), might be used to set the head-direction parameter at a prelexical stage. In a recent study, Christophe and colleagues (2003) provided empirical support for this view. It is likely that both rightmost prominence in the PP and low values of %V will bias infants toward an H-C organization of syntax, as well as toward a cluster of morphological and phonological properties. Leftmost PP prominence and a high %V would bias them toward a C-H syntax and possibly also toward a cluster of properties such as agglutinative morphology, simple syllabic structure, and relatively free word order. Developmental psycholinguists may consider acoustic cues that correlate with syntactic parameters a solution to the paradox that Mazuka (1996) pointed out. Indeed, without robust cues in the signal, parameter setting would fail to explain how the infant goes from the input to syntax without lexical information. However, if the child had already acquired lexical items, setting parameters would become unnecessary. If infants could rely on prosodic cues, they would be able to set at least some parameters without knowledge of the lexicon (Mehler and Christophe, 2000). Rhythm may also provide the infant with information to bias lexical segmentation toward shorter or longer words: languages in the stress group, such as English and Dutch, would tend to have shorter words (given that they have over 16 different syllabic types), while languages in the mora group (e.g., Japanese) would tend to have longer words (since they have about three syllabic types; see Mehler and Nespor, 2003).

The infant brain's response to natural speech

Since Broca's original publication (Broca, 1861), investigators have realized that there is a privileged relationship between language and the left hemisphere. For some, language acquisition is responsible for the emergence of left hemisphere superiority (Lenneberg et al., 1964; Mills, Coffey-Corina, and Neville, 1993, 1997), whereas others believe structural biases present at birth cause greater left-hemispheric activation when infants hear speech stimuli (Segalowitz and Chapman, 1980; Mehler and Christophe, 2000), mediating future aspects of language acquisition. After a flurry of studies in pursuit of answers to these questions, the availability of excellent imaging methods has allowed researchers to make progress. Two recent studies have shown that speech stimuli result in greater left-hemispheric activation in very young infants. One of these studies used optical topography to study neonates; the other study used fMRI to study 3-month-olds.

Optical Topography Peña and colleagues (in press) explored left hemisphere activity in 1-week-old neonates using a 24-channel optical topographical (OT) system. They assessed the change of total hemoglobin in response to auditory stimulation in 12 areas of the right hemisphere and 12 areas of the left hemisphere. Peña and colleagues stimulated the infants with normal speech (forward speech), with the same utterances played backward, and with silence. They found that acoustic stimulation resulted in greater activation in the left hemisphere than in the right (figure 59.2). Moreover, as the figure shows, temporal areas in the left hemisphere were significantly more activated by forward utterances than by backward utterances. No area of the right hemisphere was more activated by forward than by backward speech. This result is compelling, because backward speech (derived from forward utterances) is an optimal control for natural forward speech, since the two utterances are matched in pitch, intensity, and duration. Yet humans cannot produce either reverse prosody or some segments that appear in backward utterances, such as those that correspond to time-reversed stop and affricate consonants.

Peña and colleagues have thus demonstrated that the neonate's brain is particularly sensitive to language-like stimuli, or at least to stimuli that the human vocal tract can produce. These results attest to the early tuning of the human brain to the speech signals made by conspecifics. It is hardly necessary for the neonate to have gained experience from such stimuli in order for the brain to show the specificity of the response.

fMRI Studies In a study comparable to the one reported by Peña and colleagues, Dehaene-Lambertz, Dehaene, and Hertz-Pannier (2002) used fMRI in 3-month-old infants and found that auditory stimuli (forward and backward speech) gave rise to greater activity in the left hemisphere superior temporal lobe than did silence. Larger activations for forward than for backward utterances were found in the posterior areas of the left hemisphere (angular gyrus and the mesial parietal cortex; figure 59.3).

Both the OT and the fMRI studies found a left hemispheric superiority in processing sound stimuli. OT technology makes it possible to test neonates in a silent environment. Peña and colleagues found greater activation for forward

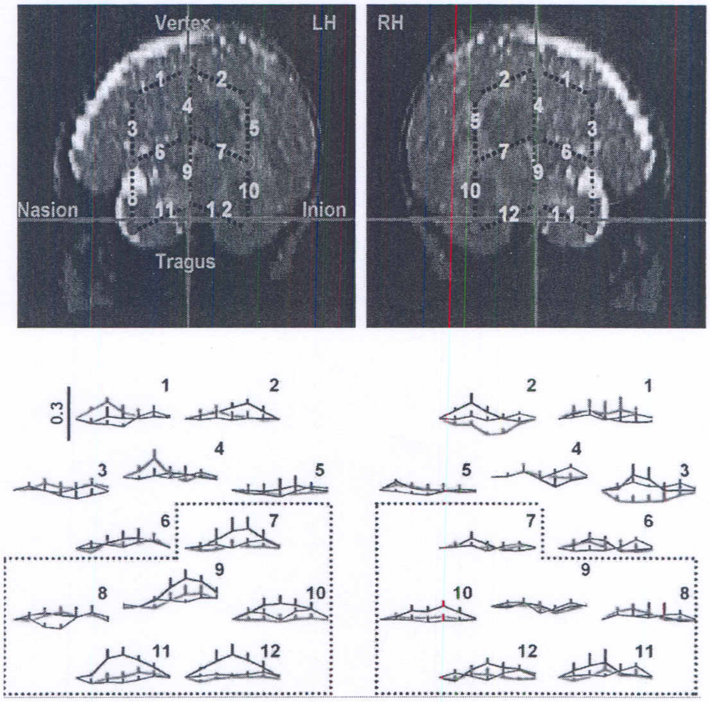

Figure 59.2 OT study of a 2-month-old infant. Top panels show positioning of the fiber-optics on the infant's head. Numbers 1 to 12 in bottom panels refer to the left and the right channels depicted in the top panels. The vertical line to the left of channel 1 in the left hemisphere shows the value of the change in concentration of total hemoglobin. Red indicates the response to forward utterances, green the response to backward utterances, and blue, the response to the control condition (silence). (See color plate 37.)

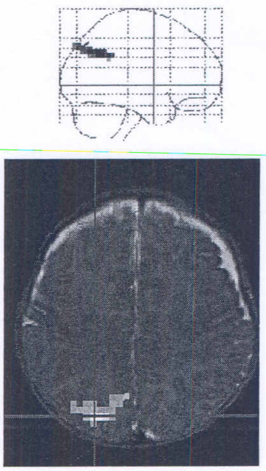

Figure 59.3 Results from the study of Dehaene-Lambertz and colleagues (2002), showing that forward utterances produced more activation in the left hemisphere angular gyrus than did backward utterances. (See color plate 38.)

than for backward utterances in the temporal areas of the left hemisphere, while Dehaene-Lambertz and colleagues found greater activation for forward than for backward utterances in the left angular gyrus and in left mesial parietal cortex in 3-month-olds. Despite the similarities of these two studies, the different results for backward versus forward utterances may reflect the fact that OT records total hemoglobin changes up to 2.5–3.0 cm from the infant's scalp, whereas fMRI can also record activations from deeper areas, such as the mesial parietal cortex. Age may also be partly responsible for the observed differences. However, it should also be noted that the older infants were tested in a magnet, that is, in a rather noisy environment, while the neonates were tested in silence.

In short, it appears from these two studies that the human brain is organized to respond to speech utterances in a specific fashion, displaying greater left hemispheric activation in perisylvian areas.

The Brain-Language Link These imaging results mesh well with the results of behavioral studies (e.g., Best, 1988; Segalowitz and Chapman, 1980; Bertoncini et al., 1989). If the initial left hemisphere advantage in processing speech indicates a language "organ," how is it possible that a patient who had failed to acquire language at 8 years could begin learning it after the damaged left hemisphere was surgically removed (Vargha-Khadem et al., 1997)? This situation indicates that the left hemisphere was blocking the ability of the right hemisphere to acquire language. Thus, it appears that the initial dominance of the left hemisphere for speech is just dominance: both hemispheres may have the potential to sustain language, but the specific cues used to signal speech are processed better by the left hemisphere. Recent work related to the cortical representation of speech and nonspeech sounds in very young infants (Holowka and Petitto, 2002) suggests that a similar left hemisphere dominance is also present for language production, and not only for language perception.

We have reviewed some of the evidence that suggests that the human brain is predisposed to language acquisition, a disposition that starts coming into play very shortly after birth. How well does this disposition adapt to different sociolinguistic conditions that the infant may encounter during language acquisition?

Bilinguals in the crib

Many studies that have investigated how grammatical knowledge is acquired have tacitly assumed that infants receive input from only one language. However, surveys show that more than half of the world's infants are confronted with input from more than one language, often from birth.

Bilingual Language Acquisition Discerning parents are amazed to notice how easily infants acquire the maternal language, or L1. Words, syntactic rules, and phonological knowledge grow ceaselessly. In less than 1 year, infants are able to identify some words, and they seem capable of extracting some of the fundamental properties of grammar (see Aslin et al., 1996; Nespor, Guasti, and Christophe, 1996; Jusczyk, 1997; Christophe et al., 2003). This is a striking achievement, yet it is even more striking to learn that very young infants have little if any difficulty learning two or more languages simultaneously. When one compares the achievement of infants with that of adults who are trying to learn a new language, let alone two, it becomes evident how powerful infants' language acquisition device is. Learning a new language is not as easy for adults as it is for infants. It is highly exceptional for individuals to attain a level of competence in a second language (L2) acquired after puberty comparable to that which is normally attained in L1 (see Johnson and Newport, 1989; Mayberry, 1993).

The Vowel Space Infants raised with two rhythmically similar languages, Catalan and Spanish, were tested when they were $4^1/_2$ months old. The results showed that they were able to discriminate the two languages (Bosch and Sebastián-Gallés, 2001a). Therefore, the ability to sort languages that are in the same rhythmic class is attained much before the infant acquires lexical items, and before the monolingual infant identifies the phonemes in its maternal language (see Kuhl et al., 1992; Werker and Lalonde, 1988).

Because Spanish-Catalan bilingual infants cannot use rhythm to separate their languages, what other cues might they use to achieve separation? Several experiments may help answer this question. In one experiment, infants from monolingual Spanish families and monolingual Catalan families were tested to evaluate whether they were able to discriminate between Catalan and Spanish, as well as Italian (a Romance language) and English (a Germanic language), at $4^1/_2$ months of age (Bosch and Sebastián-Gallés, 2000a). Previous experiments with neonates and 2-month-olds had established that they fail to discriminate languages that belong to the same rhythmic class (see Mehler et al., 1988). In contrast to the procedure used to test neonates and 2-months-olds, Bosch and Sebastián-Gallés (2000a) used natural utterances in their experiments. Spanish has five vocalic phonemes, Italian has seven, and the five vowels common to the two languages have similar frequencies of occurrence. In contrast, Catalan has eight vowels, and its most frequent vowel is absent from both Italian and Spanish.[4] If infants are paying attention to vowel frequencies, they might be able to segregate Catalan utterances from both Spanish and Italian but would fail to discriminate Spanish from Italian.[5]

The results established that monolingual infants distinguish Catalan from both Spanish (as do Spanish-Catalan bilinguals) and Italian; however, they fail to distinguish Spanish from Italian. These results suggest that segmental distribution may provide information to individuate utterances as belonging to one or the other language that are in the same rhythmic category. Although by $4^1/_2$ months of age such distributional properties are used, we do not know whether younger infants perform similar computations.

Recent studies testing $4^1/_2$-month-old and 6-month-old bilingual Spanish-Catalan infants compared a native language (the one spoken by the mother) with a nonfamiliar language. These bilingual infants discriminated between their maternal language and a foreign language, regardless of whether it was in the same or a different rhythmic class (English and Italian were used) (figure 59.4).

The bilingual infants' pattern of results contrasts with that of the monolingual infants (Bosch and Sebastián-Gallés, 1997; 2001b). As shown in figure 59.4, bilingual infants orient faster to English and Italian than to Spanish or Catalan. Hence, 4-month-old bilingual infants may be aware that two languages are used in their environment. These results indicate that cognitive mechanisms (e.g., executive functions) may differ in matched monolingual and bilingual infants.

Taken together, the results indicate that bilingual infants attain the ability to differentiate languages of the same

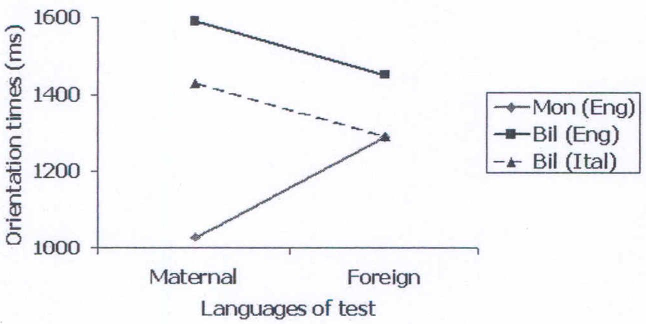

FIGURE 59.4 Figure shows mean orientation latencies of $4\frac{1}{2}$-month-old infants from monolingual environments (either Catalan or Spanish) to maternal and English sentences (in gray; Mon (Eng)), and mean orientation latencies of infants from bilingual Spanish-Catalan environments to maternal and English sentences (solid black; Bil (Eng)) and maternal and Italian sentences (dashed black; Bil (Ital)). Monolingual infants oriented faster to the familiar (maternal) than to the unfamiliar (English) language. Bilingual infants showed the opposite pattern, they oriented slower to the familiar (language of the mother) than to the unfamiliar language. This pattern of results is observed both for an unfamiliar language within the same rhythmic category as the language of the mother (Italian) and for a language from a different rhythmic group (English). (Adapted from Bosch and Sebastián-Gallés, 1997.)

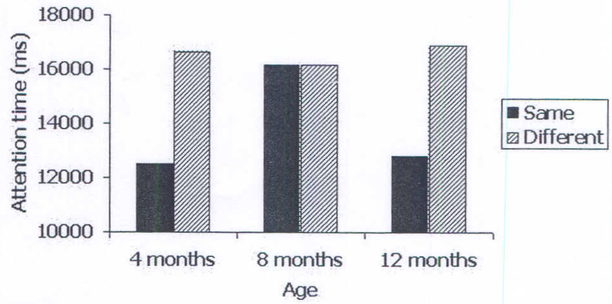

FIGURE 59.5 Time course of bilingual infants' discrimination capacities (as shown by the differences in mean attention times to same and different trials) to a Catalan-specific contrast (/e/-/ɛ/) during the first year of life. (Adapted from Bosch and Sebastián-Gallés, in press.)

rhythmic class earlier than monolingual infants. Future research may uncover whether this bilingual advantage arises when infants are asked to judge the familiar language against an unfamiliar language in the same rhythmic class. Whatever the outcome of those experiments, the refined discrimination ability of bilingual infants highlights the importance of perceptual learning.

At 6 months, monolingual infants respond preferentially to the vocalic contrasts used in their native language, and they appear to be attuned to vocalic contrasts earlier than to consonantal contrasts (Werker and Lalonde, 1988; Kuhl et al., 1992). Bilingual infants have a different developmental pattern than monolingual infants (Bosch and Sebastián-Gallés, in press). Four-month-old and 8-month-old infants from monolingual (Spanish or Catalan) and bilingual (Spanish-Catalan) households were tested on a vowel contrast present in Catalan but not in Spanish: /e/-/ɛ/ (/de'di/ versus /dɛ'di/). As expected, younger infants were able to perceive this contrast independently of the language of exposure, presumably on the basis of acoustic differences. By 8 months, infants from Catalan monolingual environments distinguished this contrast, but bilingual infants and Spanish monolingual infants did not. The behavior of the Spanish monolingual infants conformed to the previously attested decline in discrimination of contrasts that are absent from the linguistic input. The bilingual infants' behavior was unexpected, since they had received sufficient exposure to the /e/-/ɛ/ contrast. The bilingual infants receive exposure both to the /e/-/ɛ/ vowels and to the Spanish /E/ that falls between the two Catalan vowels. Possibly, the vowel space in the pertinent region becomes so crowded that the infants represent a continuous distribution that gives rise to the infants' difficulty in discriminating the Catalan contrast (see Maye, Werker, and Gerken, 2002). Bilinguals infants, however, are also less frequently exposed to the Catalan /e/-/ɛ/ contrast than the Catalan monolinguals. To evaluate these conjectures, bilingual infants were tested with a vowel contrast existing both in Catalan and Spanish: /o/-/u/. At 8 months, bilingual infants failed to discriminate the two vowels, suggesting that mere exposure may not be sufficient to preserve the capacity to perceive a contrast. Furthermore, these results suggest that the phonetic representations of bilingual infants are not identical to those of monolingual infants until a few months later. Indeed, at 12 months, Spanish-Catalan bilingual children have no difficulty distinguishing /e/ from /ɛ/ or /o/ from /u/ (figure 59.5).

At this time, it is difficult to construct an accurate model of how bilinguals cope with the vowel space or with consonantal categories. What is clear, however, is that there are systematic behavioral differences between bilingual and monolingual infants that disappear by the time the infants begin to acquire the lexicon.

Phonotactics and the lexicon

At 6 months, infants start learning phonotactic regularities, that is, how segments co-occur (for a review, see Jusczyk, 1997). Phonotactic information is language-specific. For example, in English, words with an initial [s] can have another consonant to the right of [s]—*sphere*, *strategy*—whereas the corresponding Spanish words are *esfera* and *estrategia* because of the illegality of word-initial *s*+consonant clusters. To learn the phonotactics of their languages, bilingual users must segment speech into words and acquire separate lexicons for each language. Thus, it is possible that learning phonotactics may pose a problem for bilingual infants, particularly when they are raised with rhythmically similar languages in which prosodic cues do not mediate the segregation of utterances into language files.

Bilingual infants might first concentrate on one of their two languages, filtering out or ignoring the other language, or they might try to work on both languages in parallel. Presumably the second scenario is more likely when the languages that have to be mastered belong to two separate rhythmic classes; however, when the languages belong to the same class, such as Spanish and Catalan, the most likely prediction is that the infant will either be confused or will separate the languages on the basis of nonrhythmical cues.

If bilingual infants neglected one language, they should behave in their dominant language as monolingual infants do. If they do not, they might be acquiring the phonotactics of both languages simultaneously. However, bilingual infants receive half as much exposure in either one of the languages as monolingual infants, which might lead us to predict that bilingual infants will not behave exactly as monolingual infants in either case. Thus, bilingual infants may either have a similar performance in both languages that is inferior to that of monolingual infants or a performance that is better in one of the two languages but still not as good as that of monolingual controls for the dominant language.

Nine-month-old monolingual infants prefer to listen to lists of stimuli that conform to the phonotactics of their maternal language (Jusczyk, Luce, and Charles-Luce, 1994). Sebastián-Gallés and Bosch (2002) tested 10-month-old monolingual and bilingual Catalan-Spanish infants. They evaluated the infants' responses to items with Catalan phonotactic patterns that are absent in Spanish. Unlike Catalan, Spanish does not allow complex consonant clusters in word-final position. Therefore, a word ending in two or more consonants does not exist in Spanish. Although Catalan accepts word-final complex consonant clusters, not all consonant clusters are possible. (For instance, *pirn* could be a possible word in Catalan, but not *pikf*.) According to Jusczyk, Luce, and Charles-Luce (1994), monolingual Catalan infants should show a preference for the legal words when presented with lists containing legal or illegal word-final consonant clusters in Catalan. In contrast, Spanish monolingual infants ought to show no preference, since both types of stimuli are illegal in Spanish.

Sebastián-Gallés and Bosch (2002) confirmed these predictions (figure 59.6). The bilingual infants who had been mostly exposed to Catalan behaved as the monolingual Catalan infants, while the infants who had been mostly exposed to Spanish behaved as Spanish monolingual infants, showing no preference for one or the other type of stimulus. These results are more consistent with the hypothesis that, when acquiring phonotactic knowledge, bilingual infants focus on one language first rather than acquiring both systems in parallel or a single common system for both languages.

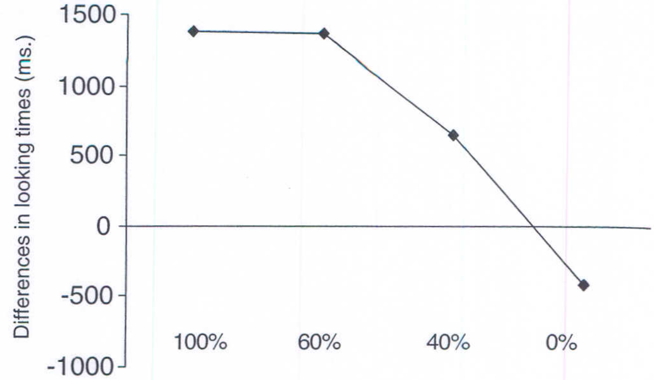

FIGURE 59.6 Sensitivity to Catalan-specific phonotactic constraints (mean differences in looking times for legal versus illegal Catalan codas) as a function of Catalan exposure (100% Catalan-monolingual infants, 0% Spanish-monolingual infants). (Adapted from Sebastián-Gallés and Bosch, 2002.)

Bilingual infants show language discrimination capacities that challenge the view that they are confused during early language acquisition. Moreover, the results presented suggest that bilingual infants display acquisition patterns that differ from those of monolingual infants. The neural substrate and the mechanisms responsible for these differences remain to be unveiled.

Unusual acquisition scenarios

The way in which the brain represents language has mostly been studied in adult monolingual university students or in patients. Here we present studies of special bilingual populations that are important because they inform us about the reliability of the language acquisition device and how it manifests itself under different conditions.

NEURAL REPRESENTATIONS OF L1 AND L2 IN BILINGUAL INDIVIDUALS Studies of highly proficient English-Italian and Catalan-Spanish bilingual individuals show that when participants listen to either of the languages, mostly very similar perisylvian areas of the left hemisphere are activated (see Perani et al., 1998). Likewise, Kim and colleagues (1997) studied a group of bilingual participants who had to implicitly produce short stories. The authors reported that the activations of L1 and L2 were indistinguishable from one another in participants who had acquired L2 early in life. Neville and colleagues (1998) studied English and American Sign Language (ASL) bilingual individuals and found that the left hemisphere perisylvian areas were activated similarly by English and ASL. This study included a group of participants who had acquired ASL and English during infancy. In these participants, oral and sign languages also activated overlapping areas of the left hemisphere. Moreover, a greater right hemisphere involvement was observed for ASL

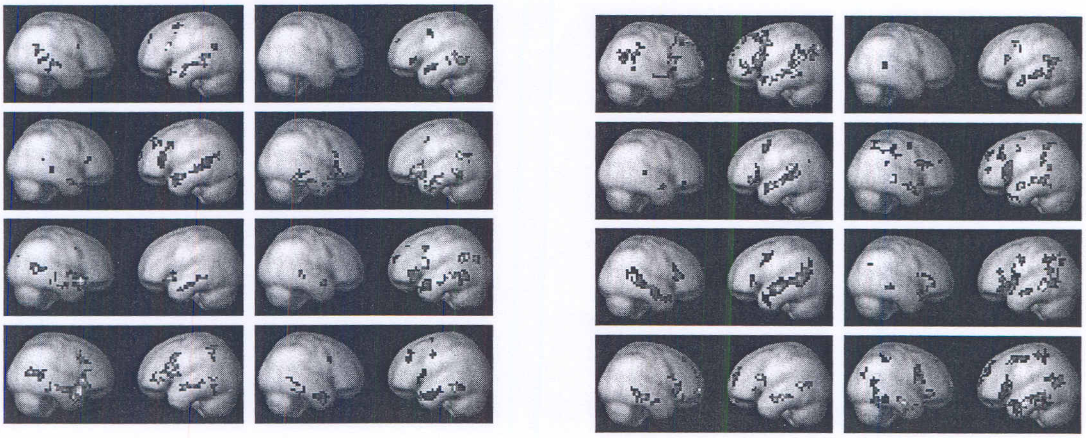

FIGURE 59.7 The eight panels on the left depict cortical areas that showed significantly greater activation when native Koreans were processing French compared to Polish utterances. The eight panels on the right illustrate the cortical areas that showed significantly greater activation when native French speakers were processing French compared to Polish utterances. Although both populations had become equally fluent in French, a significantly greater area of the left hemisphere was activated in the native French speakers than in the native Korean speakers. (See color plate 39.)

than for English (Paulesu and Mehler, 1998). A subsequent study (Newman et al., 2002) confirmed the involvement of both the right hemisphere and the left hemisphere in native ASL users and in highly proficient bilingual participants processing ASL. It is difficult to specify the role of the right hemisphere in ASL speakers. Aphasias in native users of ASL mostly arise after left hemisphere lesions, in contrast to what brain activation studies might suggest. Some researchers attribute the right hemisphere involvement in ASL processing to the spatial nature of signs and to the superiority of the right hemisphere in processing biological motion. But as Newman and colleagues point out, "The exact role of the RH in ASL processing has yet to be determined" (2002, p. 78).

Thus, a comparison of activation studies of oral-oral and oral-sign bilinguals suggests the following: (1) the oral-oral pairs show activation in overlapping areas of the left hemisphere in participants who have attained a high degree of proficiency in both languages, and (2) highly proficient oral-sign bilingual individuals have similar left hemisphere representations, but only native signers recruit larger areas of their right hemisphere. Thus, it appears that the modalities of the bilingual individuals' languages may affect the extent to which the neural representations overlap.

LOSING L1 Imaging has also been used to investigate whether a normally acquired, then forgotten L1 affects the way in which a later-acquired language is represented and processed. Pallier and colleagues (2003) studied eight Korean children who had been adopted by French families when they were more than 3 but less than 8 years old. These participants' French was indistinguishable from that of French monolingual participants on a number of behavioral tasks. After adoption, the participants' contact with Korean speakers was nil. Participants were given a number of behavioral tests and also took part in an event-related fMRI study.[6] Like the native speakers of French, in a classification of Korean and Japanese sentences, the Korean participants failed to identify the Korean utterances. In word recognition the Koreans and the control group were at chance levels. In figure 59.7 we display, for each one of the eight participants, the results of the imaging study in a French-Polish comparison. Polish may be considered the baseline condition because it was equally alien to Korean and native French participants.

The network activated by French in Korean participants is similar to the network described in previous studies on native French volunteers (see Mazoyer et al., 1993; Perani et al., 1995; Dehaene et al., 1997). Indeed, the network includes perisylvian areas in the left hemisphere, the pars triangularis, the left inferior frontal gyrus, and, to a much lesser extent, some contralateral temporal areas. The individual results for the French-Polish comparison uncover an interesting difference—the Korean group showed less extensive activation than the native French group. Interestingly, in the French-Korean comparison, a comparison that is critical to understanding whether some latent Korean is still present in the adoptees, the two groups were statistically alike. The study by Pallier and colleagues (2003) shows that the maternal language can be entirely reduced in participants who learned L1 for 3 or more years before switching exclusively to L2. Neither behavioral nor imaging data show differences between adopted participants and native French participants with respect to the Korean sentences.

Retraining experiments are helpful to assess whether despite these observations, some latent "knowledge" of L1 remains present. Ventureyra and colleagues (in press) reported results of behavioral tests on two groups of adopted

Koreans. One group had never been reexposed to Korean after learning French, while the other group had been reexposed to Korean after French had become their "native" language. The authors tested whether these groups could perform better on the discrimination of Korean contrasts than the native French speakers who have great difficulty discriminating the selected contrasts. The authors report that both groups of Koreans performed similarly to native French users. Thus, reexposure does not have an effect, since the two adopted Korean groups did not differ from one another.

The authors suggest that the usual problems encountered when learning an L2 after puberty may be due to the interference of L1 rather than to the crystallization of L1. However, we still can ask why interference is critical only if L2 is acquired after puberty. Indeed, children under the age of 10 tend to have little difficulty acquiring a second language when fully immersed in a different culture.

Conclusions

Recent studies of language acquisition have explored specific conditions that inform us about the robustness of the "language instinct." Imaging studies have strengthened our belief that the perisylvian areas of the left hemisphere are attuned to language long before the infant gains much experience about his or her surroundings. Furthermore, studies of the rhythmic properties of a fairly large number of languages have uncovered a correlation of syntactic and morphological properties with rhythm. This raises the possibility that such low-level cues might bias infants toward setting a parameter in one of its possible values. A number of future investigations will no doubt explore this conjecture in greater detail.

In this chapter, we have stressed the importance of studying the acquisition of language in realistic contexts. It is still unknown how the acquisition of language in bilingual societies affects language acquisition. We have presented a review of some investigations of Catalan-Spanish bilingual infants that will be complemented by a parallel study of infants raised with Basque and Spanish, the aim being to determine how the distance between the languages of the bilingual infant might affect the acquisition processes.

We ended with a review of some rather unique language acquisition situations that might clarify our views about standard circumstances. We have seen how differences in the modalities of the languages of the bilingual person might affect the neural representations of the two languages. We also reviewed a study of adults who had been adopted after having acquired, then forgotten, their maternal language. The study shows that such individuals are indistinguishable from native speakers of the adopted language. Imaging and behavioral studies failed to detect evidence of a residual knowledge of L1. Some hypotheses about how these studies may help understand the more habitual bilingual learning situation were considered.

Throughout this chapter, we have tried to illustrate how pervasive the nature of the stimulating environment may be in triggering different processes. In our view, the evidence presented suggests that humans are attuned to specialized signals that trigger specific computations and biases.

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NOTES

1. Stress timing assumes that there is the same duration going from any one stress to the next. Syllable timing assumes that all syllable have roughly the same duration. Mora timing assumes that subsyllabic units (roughly CVs, syllabic Vs, geminates, and nasal segments in coda position) are equal in duration.
2. We are grateful to Dan Slobin for having suggested this as an additional property of languages that have a high %V.
3. Informally, a phonological phrase includes a syntactic head and all the elements that precede it in H-C languages or that follow it in C-H languages.
4. Specifically, whereas about 25% of Spanish and Italian vowels are mid-back ones (Spanish and Italian vowel /o/ and Italian vowel /ɔ/), in Catalan only 8% are mid-back vowels. In fact, in Catalan, central vowels /a/ and schwa count for more than half of the total number of vowels in fluent speech, whereas central vowels represent less than 25% of the vowels in either Spanish or Italian that have only [a].
5. In all the studies mentioned in this section, bilingual infants were exposed to both languages in a range varying from 50%/50%, that is, equal exposure to both languages, up to 35%/65% in the most unbalanced situation (in some studies the most unbalanced situation was 40%/60%).
6. Subjects had to listen to sentences in Korean, Japanese, Polish, Swedish, and Wolof and rate whether sentences were Korean or not, using a seven-point scale. Participants also read a series of French words; each visual word was followed by two spoken Korean words, and they had to guess which of the two was the corresponding translation. Participants also took part in an event-related fMRI procedure while listening to sentences in French, Korean, Japanese, and Polish. Three native speakers of each language had recorded the sentences used in this part of the experiment. While they were being scanned, participants had to judge whether a fragment belonged to the previously heard sentence or not. The aim of this task was to equalize the attention that the participants were paying to the utterances.

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