

LANGUAGE AND COGNITION

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Abstract¹

The 4000 or so human languages display an extraordinary surface diversity; therefore language learning by the infant requires some plasticity. We present here psycholinguistic data suggesting that there are nevertheless some limits on this plasticity. In the first part, we document a “foreign listening syndrome”, that is the fact that people listen to foreign speech sounds through the filter of the phonology of their own language (a perceptual equivalent to a foreign accent in production). Even very good bilinguals seem to retain a dominant language. It thus seems that the perceptual system is shaped by early linguistic experience and stays rather rigid afterwards. In the second part, we show that very young babies are able to distinguish between languages, which is a pre-requisite if they are to learn from more than one language. In the third part, we present data from brain-imaging techniques (PET and fMRI) that investigate the cortical representation of speech in more or less

proficient bilinguals. The cortical representations of the second language show more inter-individual variability than the ones for the first language, all the more so when the second language is less well mastered and/or has been acquired later in life.

Résumé

Les quelque 4000 langues humaines montrent une extraordinaire variabilité de surface; par conséquent l'apprentissage du langage par l'enfant requiert de la plasticité. Nous présentons des données psycholinguistiques qui suggèrent qu'il y a néanmoins des limites à cette plasticité. Dans la première partie, nous décrivons le phénomène de «l'accent étranger en perception», c'est-à-dire le fait que les gens écoutent les sons de parole étrangers à travers le filtre de leur propre phonologie (un équivalent perceptif à l'accent étranger en production). Même de très bons bilingues semblent garder une langue dominante. Il semble donc que le système perceptif est façonné par l'expérience linguistique précoce, et qu'il reste relativement rigide par la suite. Dans la deuxième partie, nous montrons que des bébés très jeunes sont capables de distinguer entre différentes langues, ce qui est nécessaire pour que leur apprentissage du langage puisse se faire à partir de plus d'une langue. Dans la troisième partie, nous présentons des données d'imagerie cérébrale (TEP et RMN fonctionnelle) qui étudient les représentations corticales de la parole chez des bilingues plus ou moins compétents. Les représentations pour la seconde langue montrent plus de variabilité interindividuelle que celles pour la première langue, et ceci est d'autant plus vrai que la seconde langue est moins bien maîtrisée ou a été acquise plus tardivement.

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To gain insight into the way in which a species-specific faculty is biologically determined and then shaped by the environment is essential for anyone who has set out to understand the nature of the mind. After more than one-hundred and fifty years of research, theoretical insights are only just beginning to emerge from the accumulated observations. In this paper, we will present some recent developments that may help us glean a much better understanding of the biological foundations of language.

Since Broca's 1861 seminal paper, it has been known that the third frontal convolution is the locus of *articulated language*. The contributions of Wernicke, Dejerine, Alajouanine and more recently Geschwind, among many others, have shown that the language function spreads over other regions of the temporal, parietal, and frontal cortex in the left hemisphere (Geschwind & Levitsky, 1968). This view has become standard and is taught to all the students in the field of neuropsychology. However, knowing which areas of the cortex, when damaged, are responsible for language disorders does not clarify how such structures come to sustain the language(s) acquired by a speaker.

Chomsky (e.g., 1975) has proposed that the study of a complex cognitive function like language should be conducted in the same way as that of any other complex body organ. The language "organ", however, is rather special in two ways. First, it is productive rather than stereotyped, and speakers can generate an infinitely large number of sentences that other speakers can understand. Second, it depends crucially on early language input: Speakers can learn English, Chinese, French or any other of the four-thousand or so recorded natural languages. This input needs not even be speech, since children exposed to a sign language learn it as readily as any oral language, even though it rests on a motor-visual rather than an auditory-vocal loop. These two facts taken together make language a very special mixture of constraints and plasticity. Since all adults from a linguistic community reach the same grammatical competence despite the fact that they have been exposed to different sentences, there must be constraints on what a human language can be. However, there are many differences between languages, and only what is shared by all languages of the world can be an innate

constraint (it is the project of the Universal Grammar to discover the set of properties shared by all languages of the world). Anything that differs between languages has to be learned by children from the linguistic input they receive.

Lenneberg (1967) documented an observation that is spontaneously made by many naive observers, namely, that when language is acquired after puberty, only partial proficiency is gained regardless of the efforts made (the extent of the limitations in late-acquired language continues to fuel debate today). Lenneberg, among others, used this observation to argue in favor of a sensitive period or window during which impeccable language acquisition can take place. This notion is congruent with the view that language learning is innately guided. Many innately guided learning mechanisms observed in animals or humans have been found to have a critical period during which input from the environment is allowed to shape the system as it will work in the adult organism (e.g., sound localization in the barn owl, Knudsen & Knudsen, 1986; or, the very extreme case of imprinting as described by Lorenz). More recently, Weber-Fox and Neville (1996) have found that "maturational changes significantly constrain the development of the neural systems that are relevant for language" (p. 231), based on data from a population of bilingual subjects varying in age of acquisition of the second language. Similarly, Hickok, Bellugi, and Klima (1996) have shown that in native speakers of American Sign Language, the cortical regions where language is represented correspond to the regions that have been determined in speakers of oral-vocal languages. On this basis, they argue that left-hemisphere specialization for language is a characteristic of language itself, in its abstract shape, rather than a by-product of sensory or motor factors. These evidence suggest that the parts of the cortex that are devoted to the mediation of higher cognitive skills display a rather considerable rigidity and a fixed developmental pattern.

However, recent results from the cognitive neurosciences have raised skepticism about the existence of critical periods. The brain of vertebrates has been shown to have an astonishing plasticity. Indeed, Kaas, Merzenich and Killackey (1983) and Kaas (1991) have reported that learning can result in

processing gains throughout the organisms' life through the alteration of the cortical maps underlying sensory functions. An example of exogenous conditions resulting in the functional reorganization of the brain was provided by Sugita (1996) who has shown that the adult visual cortex can undergo extensive functional reorganization in response to the reversal of the retinal projections by prisms. Sadato et al. (1996) have found that blind individuals who are asked to discriminate Braille dots have a significantly greater blood flow, as compared to sighted controls, in the primary visual cortex. This result suggests that when the primary visual cortex is no longer activated by visual input it can become activated by touch. Rauschecker and Korte (1993) have shown that in blind cats there is compensatory auditory representation which is believed to have arisen by expansion of auditory areas which invade the visual areas. In a recent review of compensatory plasticity in cortex, Rauschecker (1995) has concluded that plasticity might not "be restricted to developmental periods, but may be available, at least to some extent, throughout life" (p. 42). Of course, most of the research reviewed by Rauschecker is concerned with the representation of spatial cognitive maps and the possibility of remapping these on the basis of sensorimotor feedback. It may be that such plasticity would not apply to a much more complex cognitive function such as language.

But in the domain of language itself, Tallal and her colleagues (1996) have illustrated the brain's plasticity by providing extensive training to language-learning impaired children. They trained the children with rate-modified speech and temporal discrimination tasks and noted great improvement in their performance. Interestingly, these rapid gains were made with children whose age ranged from 5 to 10 years. Even more recently, Vargha-Kahdem and her colleagues (personal communication, 1996) have reported the case of a child who was able to acquire language after the age of 9, when his damaged left hemisphere was removed. This suggests that language can be learned on the basis of the residual abilities of the right hemisphere if the inhibitory action of the damaged left hemisphere is removed even at a rather advanced age. In this view, then, inadequate language learning after a given age would not be attributed to the existence of a

critical period, but rather to other reasons such as differences in motivation, inhibition from competing cognitive resources, etc.

We have arrived at a point where we can clearly state the controversy. On the one hand we have this view of almost unlimited cortical plasticity. On the other hand, the view that language learning is very much constrained is based on arguments coming from formal analyses (linguistics and learnability theory), brain-damaged patients, brain imaging, etc. This controversy is all but insignificant; whether language calls for a specialized learning system that only humans possess is one of the essential questions that students of the biology of language need to answer.

How can psycholinguistic research shed light on this controversy? We will review work aimed at evaluating in more detail how second language learners are impaired, depending on when they acquired their second language and on the similarities between their first and second languages. We will argue that late learners do not just acquire a foreign accent but that they are also affected by a foreign listening syndrome when confronted with speech stimuli not in their first language. In addition, even highly proficient bilingual subjects, who learned both languages in infancy, seem to be incapable of escaping from the perceptual dominance imposed by their first language. We will then review some infant studies suggesting that babies manage to solve part of the problem of distinguishing their mother tongue from foreign language input, a crucial prerequisite for successful language acquisition in babies exposed to more than one language. Finally, we will attempt to tackle the issues of early bilinguals and critical periods through imaging work with a variety of bilingual populations. We will present some imaging results, based on both PET and fMRI studies and argue that there seems to exist a corresponding asymmetry between the brain representations of first and second languages. While a major network in the left hemisphere is consistently dedicated to first language processing across subjects and languages, the way in which a second language is represented by subjects' brain varies greatly, as does the way in which this second language was acquired. This variability is more salient in less proficient bilinguals than it is in more proficient bilinguals.

Contrasting Language Processing Schemes

Psycholinguistics' default assumption has been that all languages are processed in much the same way up until the lexicon is accessed. It has been known for a long time that the collection of segments varies from one natural language to the next, and that speakers who have to process segments not present in their mother tongue often have trouble hearing them. In addition, early infant speech perception research has established that babies in their first year of life can process segmental contrasts from all human languages, and that only towards the end of the first year of life do they start performing like adults from their linguistic environment (Best, McRoberts, & Sithole, 1988; Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Werker & Tees, 1984). From these data, one can entertain the hypothesis that speech processing mechanisms are identical from one language to the other, at least as far as access to words is concerned, and that the only differences between languages lie in the inventories of phonemes and of words (which have to be learned).

More recent research has established that the syndrome we would like to call the *foreign listening syndrome* cannot be reduced to differences in the inventory of phonemes. Indeed, Mehler, Dommergues, Frauenfelder, and Segui (1981) have shown that the syllable is a pre-lexical unit that plays an important role for speakers of French (this result was later extended to other Romance languages, see Sebastian-Galles, Dupoux, Segui, & Mehler, 1992). Two years later Cutler, Mehler, Norris, and Segui (1983) reported that native English speakers tend to attach more importance to a metrical unit beginning with a strong syllable, than to syllables themselves (this result was later extended to other stress-timed languages, see Vroomen & de Gelder, 1995). Otake, Hatano, Cutler, and Mehler (1993) have more recently noted that in response to the very same acoustic items, Japanese, English and French subjects behaved differently: Each population analyzed the stimuli in a manner congruent with the properties of its native language. The general conclusion of our Human Frontiers Science Program consortium of psycholinguists was that speakers of French, English, Japanese, Spanish, Catalan, and so forth use processing

routines that are ideally tailored to exploit the properties of their native language.

More recently, Dupoux, Pallier, Sebastian, and Mehler (in press) observed a striking contrast between the way French and Spanish subjects process accentual information. While accent is contrastive in Spanish (as evidenced by minimal pairs such as *bébe* vs. *bebé*, that mean "baby" and "drink!" respectively), it consistently falls on the last syllable of words in French. In an ABX task, in which subjects had to judge whether the last of three nonsense words (pronounced by native speakers of Dutch) sounded more like the first or the second item heard, Spanish subjects were shown to be fast and accurate when processing stress contrasts (see Figure 1, top panel), and were unable to ignore stress information when it was irrelevant and they had to pay attention to phoneme information only (see Figure 1, bottom panel). In contrast, French subjects experienced considerable difficulty with the stress contrast (see Figure 1, top panel) while it was very easy for them to ignore irrelevant stress information (see Figure 1, bottom panel).

Figure 1 about here

Another example of foreign listening can be observed when speakers of Japanese have to process items with consonant clusters (Dupoux et al., 1997). Japanese is a language that does not allow for these clusters (with the exception of VNCV where the N is a sub-syllabic mora). When confronted with a cluster in an imported word, speakers of Japanese report hearing an epenthetic vowel between the consonants. This is due to the fact that they are not able to distinguish between the nonwords *ebzo* and *ebuzo* in an ABX task: To them, both nonwords are homophonous (see Figure 2). In contrast, they can easily process a vowel length contrast (*ebuzo* vs. *ebuuzo*) which is linguistically relevant in Japanese. French subjects show exactly the reverse pattern, since consonant clusters are accepted in French but vowel length is not linguistically relevant.

Figure 2 about here

Accent deafness in the French and epenthetic vowel insertion in the Japanese are

both examples of the foreign listening syndrome, a phenomenon equivalent to the well-attested foreign accent observed in speech production. These facts reflect the large extent to which one recodes inputs (and outputs) in order to render them compatible with the structures one has acquired when learning a first language. Indeed, one is tempted to claim that the French do not compute stress at all (they would instead automatically attribute it to the last syllable of any perceived string). Likewise, the native speakers of Japanese will arrange inputs to fit into the CVCV grid that their knowledge of Japanese has led them to take for granted.

There are many other studies that illustrate the foreign listening syndrome. However, our purpose here is not exhaustivity. So, let us accept the conjecture that when one learns a language in infancy, one tends, later on, to use that knowledge to process any string of speech, even if it is in a foreign language. If an item has a badly formed sound structure, one will encode the signal in the way that falls nearest to that in one's native language. But what happens for people who learn more than one language during early childhood? Will bilinguals be able to perform with both of their languages like monolinguals in either language? Will they strike a compromise that places them half way between the two languages? Or, will they always be more proficient in one of the languages and try to find ways for coping with their second language in the most efficient fashion given that their first and dominant language is there?

Cutler, Mehler, Norris, and Segui (1989) have reported that even highly proficient French-English bilinguals who learned both languages before the age of 4 behave as if they had a first language that dominates their second language (even though it is not very easy to determine solely from the subject's history of exposure to both languages which is first and which second). Likewise, Weber-Fox and Neville (1996) have shown that adult Chinese-English bilinguals exposed to English (their second language) for the first time from one to three years after having begun exposure to Chinese (their first language) displayed some impairment in English because of the time lag (this was especially true of their syntactic processing). This state of affairs obtained despite the fact that these people had lived in the US from the age of 3 and had

spoken English from then on. Nevertheless, they still were less proficient in their second language than monolingual speakers of English. Another study that shows a similar pattern of results was carried out by Pallier, Bosch, and Sebastian-Gallès (1997) who found that vowel processing differed in bilingual speakers of Spanish and Catalan depending on whether they were dominant in Spanish or in Catalan. Their subjects had lived all their lives in Catalunya, a very bilingual community. Only people who had a clearly established family language (i.e., both parents spoke Catalan, or both spoke Spanish) participated in this study: The family language was therefore their dominant language. Their schooling and daily life were well balanced between the two languages. Nonetheless, their perception of vowels depended clearly on the language first heard in the crib.

These results illustrate a lack of functional plasticity, even for very low-level perceptual capacities, that contrasts with the evidence reported above suggesting that the brain has considerable plasticity. What do these contrasting results tell us about language learning and brain plasticity? This is what we wish to examine in the remainder of this paper. We will start by reviewing results about how babies start acquiring the specific properties of their native language during the first year of life. Then we will consider how the baby can cope with more than one language. We will conclude with an examination of the way in which the cortical areas of the brain are organized in monolingual and bilingual people.

The Infant's First Adaptations to Language

At the initial state, infants cannot know whether the speech they hear represents the output of several speakers, all of whom are speaking one and the same language, or the output of several speakers using different languages or from one speaker who is switching from one language to another. Infants, nonetheless, converge quite rapidly to the relevant properties of the parental language and so far, nobody has been able to document delays in language acquisition when more than one language is being used in the surrounding environment. A consequence of this is that babies must have a way of distinguishing

between languages in the course of acquisition: Otherwise, they would attempt to figure out regularities from a set of sentences coming from more than one language, and would get hopelessly confused.

In the last 10 years or so, a number of studies have clarified this important question. Bahrick and Pickens (1988) have shown that 4-month-old infants respond to a change in the language of a sentence more than to a change of sentence without a change of language. Mehler et al (1988) have observed that four-day-old French infants could discriminate between Russian and French sentences. These infants could also discriminate between Italian and English sentences (i.e., two foreign languages for them). Two-month-olds, unlike newborns, react to a change in language only when their mother tongue is contrasted with a foreign language, but not when two foreign languages are compared. This result suggests that by the time infants are 2 months old they have already extracted some of the defining properties of their first language, and that from that time on they are interested solely in exploring utterances that belong to their first language, and tend to ignore other utterances as not relevant for them. In that case, they would group all foreign languages in one category, "foreign", regardless of whether they can actually perceive differences between them or not. Much more research will be needed before we can ascertain this interpretation. It does nonetheless seem reasonable to conjecture that by the age of 2 months, infants have already extracted some of the properties that characterize their mother tongue relative to other languages. We know in addition that infants discriminate between languages on the basis of their melodic and rhythmic properties (their prosody), since the above-mentioned experiments replicate when one uses low-pass filtered speech where segmental information is almost completely disrupted (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, in press)

If infants rely mostly on prosodic information when discriminating between two languages, it seems likely that they cannot discriminate between any pair of languages. Indeed, it seems rather unlikely that sentences carry enough melodic information to allow for unambiguous identification of the language from which they are drawn. A more reasonable conjecture seems to be that infants sort

sentences into classes of languages based on prosody. This conjecture seems to gain some credit from recent work by Nazzi et al. (in press), who have shown that infants tend to neglect changes if languages have similar rhythmic properties. Thus, French infants fail to discriminate filtered English sentences from filtered Dutch sentences (even though they are perfectly able to discriminate between English and Japanese filtered sentences in the same setting). More convincing even that infants tend to group languages into rhythmic classes, infants have no difficulty discriminating between sets of sentences that are drawn from a mixture of languages, as long as all sentences from one set belong to the same rhythmic class, and there is a different rhythmic class for each set. Thus, French newborns react to a change from a mixture of Spanish and Italian sentences to a mixture of Dutch and English sentences (or vice-versa). In contrast, they do not react to a change from, say, a mixture of Dutch and Italian sentences to a mixture of English and Spanish sentences (see Figure 3).

Figure 3 about here

To sum up, it appears that babies are born with a capacity to distinguish at least between some pairs of foreign languages, and they seem to do so on the basis of intonation. We suggest that for those languages that are not distinguishable on the basis of intonation alone, the very first stages of language acquisition are similar, and that therefore bilingual babies would not suffer from the confusion (Mehler, Dupoux, Nazzi, & Dehaene-Lambertz, 1996). However, what is really needed is direct research on bilingual babies who are exposed to languages that are more or less distinct phonologically. In the next section, we will review some research in which brain-imaging techniques have been used to investigate the end result of the acquisition process in bilingual subjects. How are two different languages processed by the same brain?

Brain Imaging and Speech Comprehension

The cortical representation of language is one of the standard objects explored by traditional neuropsychology through the study

of clinical patients who have lost language or parts of it following trauma. A lot has been discovered and it is only in the more recent decades that methods of brain imaging have made it possible to complement such findings by exploring the organization of the cortex in healthy volunteers. Brain-imaging studies explorations were first carried out either by using the printed word as stimuli or very elementary sounds. In our group, we have focused on a more naturalistic system, namely, the speech comprehension system. Most of our studies consist in having subjects listen to spoken sentences that make up a story.

In a first set of studies, Mazoyer et al. (1993) explored how their brain is activated when subjects listen to simple stories. This was compared to a control condition where the subjects were exposed to silence. The stories were either in French, the first language of all subjects or in Tamil, a language that none of the subjects could understand. It was found that when subjects paid attention to the foreign language, the only parts of the cortex that showed a consistent increase in activity were the superior temporal gyrii, without much asymmetry between the right and the left hemispheres. In contrast, when subjects listened to French increased activity was observed in a complex left-hemisphere network that included the superior and medial temporal gyrii, the temporal pole, a frontal cortex area that coincides with what can be called an extended Broca's area and also a more frontal area, namely, Brodmann's area 8. In the right hemisphere, only the superior temporal gyrus and the temporal pole showed increased activity. It is hardly surprising that this observation coincides with what one might have expected after so many years of classical neuropsychology. Activity was observed in two unexpected areas, however, namely the temporal poles and Brodmann's area 8 and many of us found it surprising that the temporo-parieto-occipital region (often referred to as the carrefour) on the left was not observed while subjects were processing their first language.

This study tells us that the brain does not react in the same way to a story in the subjects' first language and to a story in a language unknown to them. Why is this? Is the observed network actively engaged in processing the first language because it is the subjects' mother tongue or would this network

also participate in the processing of any language that the subjects are capable of understanding?

Neuropsychology has found contrasting results concerning language representation in bilinguals. Paradis (1995) reports that aphasia can hit the first or the second language separately, in ways that seem to be consistent with the view that different languages are represented in different brain areas. Likewise, Albert and Obler (1978) have argued that the second language (L2) is represented more globally than the first language (L1) and that the right hemisphere plays a more important role in its representation. In contrast, using cortical stimulation, Ojemann and Whitaker (1978) have shown that L2 is more broadly represented in the left hemisphere than L1 but have not found much evidence for a right-hemispheric representation of L2, as suggested by Albert and Obler (1978). Recently, Breier et al. (1996) have reported on a single patient tested using the Wada procedure. This patient's L1 was Spanish although he had become equally familiar with English, his L2, a language which he claimed he spoke more often. The patient spontaneously counted and named in English. However, following a barbiturate injection in the right carotid, he switched to Spanish. In contrast, after the barbiturate was injected in the left carotid, he was unable to name in either language. Moreover, as the effect of the barbiturate tapered off, both languages were recuperated conjointly. The results from this case study suggest that L1 may be exclusively represented in the left hemisphere, whereas L2 tends to be distributed more broadly over both hemispheres. This hypothesis is consistent with the observations reported by Albert and Obler (1978). Notice, however, that it is difficult to decide definitely on this issue on the basis of a single patient. Too many parameters can change from one patient to another and we have no evidence that observations will generalize to the population of bilinguals at large. The data base can be expanded, however, using brain-imaging on populations of controlled bilinguals. We collaborated with colleagues in Milano (Italy) who had similar interests and were working on brain imaging. Most of the studies reported below have stemmed from this collaboration.

Perani et al. (1996) used the PETscan to study Italian volunteers who also spoke

English, a language they had acquired after the age of 7 (most of them after the age of 10) and which they spoke with low proficiency. These volunteers listened to stories in Italian, in English, and in Japanese (a language unfamiliar to all of them). Moreover, two control conditions were added, that is one involving listening to stories in Japanese played backwards and one attentive silence condition. When subjects listened to the stories in Italian, Perani et al. (1996) observed a pattern of activity similar to that noted by Mazoyer et al. (1993) in French subjects listening to French stories.

This replication is welcome given that the two studies used different languages, different stories and different equipments, and it strengthens our conviction that the observed pattern of activity uncovers cortical areas that are involved in the representation and processing of L1. What about the network that is devoted to the processing of L2? The cortical areas that are significantly activated in response to L2 are rather modest when compared to the network that responds to L1. The main areas include the left and right superior and middle temporal gyrii. Thus the activity respectively triggered by L1 and L2 is quite different. Interestingly, the activation in response to Japanese, a language that the subjects did not understand, was rather similar to that observed for English, which they understood. Figure 4 shows the activation patterns in all four conditions; the colored areas correspond to areas where the activation is significantly more important for one condition of stimulation than for the other.

Figure 4 about here

Perani et al. (1996) have reported that a large network of areas are significantly more active in response to L1 than to L2. Indeed, there was more activity to L1 in the temporal poles bilaterally, as well as in the left carrefour and also in the left inferior frontal gyrus. In contrast, no area was significantly more active in response to L2 than in response to a language unknown to the subjects. This result is paradoxical since the Italian volunteers were able to respond almost as correctly to the questions about the English stories as to those for the Italian stories. If brain-imaging were able to warrant interpretations like those a modern phrenologist would make, one would

be tempted to claim that there are no specific areas where the L2 lexicon, syntax, and semantic representations are located. If so, where could our volunteers have looked up the English words, and computed the syntax and semantics of the sentences in order to understand the English stories? Or could it be that they had the atavic faculty to process the Japanese stories without being aware of this faculty? Obviously none of the above possibilities is attractive. We do believe that there are some attractive alternative possibilities to explain the observations Perani et al. (1996) have reported. We consider some of them below.

One hypothesis we found quite plausible to explain the above pattern of results is that L1 is represented alike in all adults, whereas the representation of L2 varies considerably from person to person. Such a state of affairs might not be unexpected if one considers that all infants acquire their first language under very similar conditions, whereas there is great variation in the way in which L2 is learned. This state of affairs could have given rise to the pattern of results found by Perani et al. (1996). Indeed, PET results deal only with patterns that arise in all the volunteers under one condition as compared to another. Up until recently, methods of analysis made it difficult, even impossible, to evaluate individual results. Thus, Perani et al.'s results could have arisen if all subjects had the same pattern of activity when they were processing Italian but not when they were processing English. To evaluate such a conjecture, Dehaene, Dupoux, Mehler, van de Moortele, and le Bihan (1997) carried out an fMRI experiment to study cortical activity in eight native speakers of French. They presented each volunteer with passages of L1 alternating with passages of backward speech; they also presented passages in L2 in alternation with backward speech.

All subjects were low-proficiency speakers of English whose L2 performance was comparable to that of the Italians tested by Perani et al. (1996) The results, as hypothesized, show that while L1, by and large, activates the same areas in seven of the subjects, L2 activates cortical areas that differ for each subject. One subject showed a right-hemisphere activation when listening to L1. This is not entirely surprising if one bears in mind that roughly one person in ten has been

found to have language localized in his or her right hemisphere (see Bryden, 1982).

The above results are instructive because they help us understand the riddle of why previous investigations were unable to determine the cortical representation of L2 on the basis of the aphasiological data. The origin of this difficulty must be in the variability with which L2 is represented in low- or medium-proficiency bilinguals, that is, the most frequent types of bilinguals. Is it possible that in order for L2 to be represented by the same cortical structures as L1, a bilingual has to achieve a very high degree of proficiency? Or, maybe what is critical is the age at which he or she masters L2. It is quite possible that if L2 is acquired before the putative critical period comes to a close, its cortical representation will look like that of L1. Certainly, age of acquisition and degree of proficiency are two of the parameters that could influence the way in which L2 is represented. Another one may be the distance between L1 and L2. We cannot at this time rule out the possibility that a bilingual speaker of Japanese and Spanish may have representations for L1 and L2 that are different from those of a bilingual speaker of Spanish and Italian, two close languages. In our own work, we are focusing on the role of proficiency and age of acquisition.

In a preliminary study, we asked highly proficient Italian speakers of English who had all learned L2 after the age of 10 to undergo a very similar experimental procedure as the one described above with the low-proficiency volunteers. Although L1 and L2 seemed to have less distinct representations in these subjects than among low-proficiency bilinguals, significant differences remained. In another study we examined highly proficient Spanish-Catalan bilinguals who had acquired both languages before the age of 4. Again, the representations for L1 and L2 seemed to differ, although conclusive statistical analyses are not yet available. In both of these experiments with proficient bilinguals, the area observed in response to L2 appeared more extended than that for L1 (although this remains to be statistically validated). This result suggests that while L1 and L2 may rely on a similar set of cortical structures, to process the latter the volunteers engage more resources even though their apparent linguistic skill is incredibly good and the two languages extremely close to one another. We see this

result as illustrating the same point as the one recently made by Just, Carpenter, Keller, Eddy, and Thulborn (1996). On the basis of a study of the pattern of brain activation that is observed during sentence comprehension, these authors have claimed that the greater the sentence complexity, the more neural tissue will be recruited in areas that are contiguous to those present when processing simple sentences. They have used this result to caution students who are arguing in favor of a simplistic use of imagery to establish the cartography of the brain.

Our own view is that L1 relies on a definite network which is, by and large, located in the left hemisphere; additional languages acquired by people rely on structures that are associated to the network, plus on adjacent structures and, in some cases, on areas located elsewhere. In brief, it appears that even if L1 and L2 are similar languages, like Spanish and Catalan, and even if the subjects have attained a high level of bilingual proficiency, one still sees differences in the pattern of activation between L1 and L2 though, it must be granted, these differences have become minor compared to the ones reported above for the low-proficiency bilinguals.

There are many supplementary studies that need to be pursued further. Indeed, age of acquisition has been examined but in a way that remains correlated with the distance between L1 and L2. We have not yet studied bilinguals for which L1 and L2 are very distant languages; neither have we studied volunteers whose L1 has become less proficient than their L2. Nonetheless, on the basis of the results so far reported, we can already say that the language ability seems to arise because nature has endowed us with structures located in the left hemisphere (a language organ) that are particularly apt to acquire the linguistic system that is used in our environment. Moreover, if more than one language exists in this environment, the language acquisition device remains capable of coping with the multiplicity of inputs. However, in most of the behavioral studies carried out recently, as well as in the brain-imaging studies reported above, we have always failed to find a complete identity of L1 and L2. It always looks as if there is an L1 which dominates L2. What we suggest is that while L1 might have preempted the settings of switches necessary to acquire

language, the settings that are adequate to L2 will reflect in part the ones already fixed for the purpose of L1. These results taken as a whole suggest a rather rigid acquisition schedule that does not display as much plasticity as one might expect when people acquire a second language.

References

- Albert, M. L., & Obler, L. K. (1978). *The bilingual brain*. New York: Academic Press.
- Bahrack, L. E., & Pickens, J. N. (1988). Classification of bimodal English and Spanish language passages by infants. *Infant Behavior and Development, 11*, 277-296.
- Best, C. T., McRoberts, G. W., & Sithole, N. M. (1988). Examination of perceptual reorganization for nonnative speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 345-360.
- Breier, J. I., Dede, D., Fiano, K., Fennell, E. B., Leach, L., Uthman, B., & Gilmore, R. (1996). Differential effects of right hemisphere injection during the wada procedure on the primary and secondary languages in a bilingual speaker. *Neurocase, 2*, 341-345.
- Broca, P. (1861). Remarques sur le siège de la faculté du langage articulé suivie d'une observation d'aphémie. *Bulletin de la Société d'Anatomie, Paris, 6*, 330.
- Bryden, M. P. (1982). *Laterality: Functional asymmetry in the intact brain*. New York: Academic Press.
- Chomsky, N. (1975). *Reflexions on language*. New York: Pantheon.
- Cutler, A., Mehler, J., Norris, D., & Segui, J. (1983). A language-specific comprehension strategy. *Nature, 304*, 159-160.
- Cutler, A., Mehler, J., Norris, D., & Segui, J. (1989). Limits on bilingualism. *Nature, 320*, 229-230.
- Dehaene, S., Dupoux, E., Mehler, J., van de Moortele, P.-F., & Bihan, D. L. (1997). *Functional variability in the cortical representation of first and second languages*. Manuscript in preparation.
- Dupoux, E., Kakehi, K., Hirose, Y., Pallier, C., Fitneva, S., & Mehler, J. (1997). *Epenthetic vowels in Japanese: A perceptual illusion*. Manuscript submitted for publication.
- Dupoux, E., Pallier, C., Sebastian, N., & Mehler, J. (in press). A distressing deafness in French. *Journal of Memory and Language*.
- Eimas, P. D., Siqueland, E. R., Jusczyk, P. W., & Vigorito, J. (1971). Speech perception in infants. *Science, 171*, 303-306.
- Geschwind, N., & Levitsky, W. (1968). Human brain: Left-right asymmetries in temporal speech region. *Science, 161*, 186-187.
- Hickok, G., Bellugi, U., & Klima, E. S. (1996). The neurobiology of sign language and its implications for the neural basis of language. *Nature, 381*, 699-702.
- Just, M. A., Carpenter, P. A., Keller, T. A., Eddy, W. F., & Thulborn, K. R. (1996). Brain activation modulated by sentence comprehension. *Science, 274*, 114-116.
- Kaas, J. H. (1991). Plasticity of sensory and motor maps in adult mammals. *Annual Review of Neuroscience, 14*, 137-167.
- Kaas, J. H., Merzenich, M. M., & Killackey, H. P. (1983). The reorganization of somatosensory cortex following peripheral-nerve damage in adult and developing mammals. *Annual Review of Neuroscience, 6*, 325-356.
- Knudsen, E. I., & Knudsen, P. F. (1986). The sensitive period for auditory localization in barn owls is limited by age, not by experience. *Journal of Neuroscience, 6*, 1918-1924.
- Lenneberg, E. (1967). *Biological foundations of language*. New York: Wiley.
- Mazoyer, B. M., Dehaene, S., Tzourio, N., Frak, V., Murayama, N., Cohen, L., Lévrier, O., Salamon, G., Syrota, A., & Mehler, J. (1993). The cortical representation of speech. *Journal of Cognitive Neuroscience, 5*, 467-479.
- Mehler, J., Dommergues, J. Y., Frauenfelder, U., & Segui, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior, 20*, 298-305.
- Mehler, J., Dupoux, E., Nazzi, T., & Dehaene-Lambertz, G. (1996). Coping with linguistic diversity: The infant's viewpoint. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 101-116). Mahwah, NJ: Lawrence Erlbaum Associates.
- Mehler, J., Jusczyk, P. W., Lambertz, G., Halsted, G., Bertoncini, J., & Amiel-Tison, C.

(1988). A precursor of language acquisition in young infants. *Cognition*, 29, 143-178.

Nazzi, T., Bertoncini, J., & Mehler, J. (in press). Language discrimination by newborns: Towards an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance*.

Ojemann, G. A., & Whitaker, H. A. (1978). The bilingual brain. *Archives of Neurology*, 35, 409-412.

Otake, T., Hatano, G., Cutler, A., & Mehler, J. (1993). Mora or syllable? Speech segmentation in Japanese. *Journal of Memory and Language*, 32, 258-278.

Pallier, C., Bosch, L., & Sebastian-Galles, N. (1997). *A limit on behavioral plasticity in vowel acquisition*. Manuscript submitted for publication.

Paradis, M. (1995). *Aspects of bilingual aphasia*. Oxford, England: Elsevier.

Perani, D., Dehaene, S., Grassi, F., Cohen, L., Cappa, S. F., Dupoux, E., Fazio, F., & Mehler, J. (1996). Brain processing of native and foreign languages. *Neuroreports*, 7, 2349-2444.

Rauschecker, J. P. (1995). Compensatory plasticity and sensory substitution in the cerebral cortex. *Trends in Neurosciences*, 18, 36-43.

Rauschecker, J. P., & Korte, M. (1993). Auditory compensation for early blindness in cat cerebral cortex. *Journal of Neuroscience*, 13, 4538-4548.

Sadato, N., Pascual-Leone, A., Grafman, J., Ibanez, V., Delber, M. P., Dold, G., & Hallett, M. (1996). Activation and the primary visual cortex by Braille reading in blind subjects. *Nature*, 380, 526-528.

Sebastian-Galles, N., Dupoux, E., Segui, J., & Mehler, J. (1992). Contrasting syllabic effects in Catalan and Spanish. *Journal of Memory and Language*, 31, 18-32.

Sugita, Y. (1996). Global plasticity in adult visual cortex following reversal of visual input. *Nature*, 380, 523-526.

Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X., Nagarajan, S., Schreiner, C., Jenkins, W. M., & Merzenich, M. M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, 271, 81-84.

Vroomen, J., & de Gelder, B. (1995). Metrical segmentation and lexical inhibition in spoken word recognition. *Journal of*

Experimental Psychology: Human Perception and Performance, 21, 98-108.

Weber-Fox, C. M., & Neville, H. J. (1996). maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience*, 8, 231-256.

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

Figure Captions

Figure 1. Reaction times (in grey) and error rates (in black) to ABX judgments in French and Spanish subjects. Top panel: ABX on accent only, phonemes fixed (e.g., VAsuma, vaSUmA, VAsuma; correct response: first item). Bottom panel: ABX on phonemes only, accent varied orthogonally (e.g., VAsuma, faSUmA, vaSUmA; correct response: first item).

Note. From “A distressing deafness in French,” by E. Dupoux et al., in press, *Journal of Memory and Language*. Copyright 1997 by Academic Press. Adapted with permission.

Figure 2. Reaction times (in grey) and error rates (in black) to ABX judgments in French and Japanese subjects on a vowel length contrast and on an epenthesis contrast.

Note. Data from “Epenthetic vowels in Japanese: A perceptual illusion,” by E. Dupoux et al., 1997, Manuscript submitted for publication. Copyright 1997 by E. Dupoux et al. Adapted with permission.

Figure 3. Sucking rate averages in a non-nutritive sucking experiment with 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 non-rhythmic 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 non-rhythmic group.

Note. From “Language discrimination by newborns: Towards an understanding of the role of rhythm,” by T. Nazzi et al., in press, *Journal of Experimental Psychology: Human Perception and Performance*. Copyright 1997 by the American Psychological Association. Reprinted with permission.

Figure 4. 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. Note. From “Brain processing of native and foreign languages,” by D. Perani et al., 1996, *Neuroreports*, 7, p. 2441. Copyright 1996 by Rapid Science Publishers. Reprinted with permission.