

Language Acquisition: Biological Versus Cultural Implications for Brain Structure

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ABSTRACT

In the discussion on co-constructivism of culture and brain, language is particularly interesting because it is clearly a cultural construction, yet deeply rooted biologically. Cross-linguistic data strongly suggest that the same brain areas, functionally identified to be specific for syntax, semantics, and phonology, are active in participants across languages. However, comparisons between first (native) and second (nonnative) language processing reveal differences with respect to the recruitment of the different subcomponents in a common neuronal network of language processing. Native language processing thus seems to be similar across different languages, but the strategies used to process a nonnative language appear to be different.

INTRODUCTION

One of the intriguing issues discussed in the context of the nature–nurture debate (also known as the biology–culture debate) is the question of how different languages influence the brain basis of language processing. This question is particularly interesting in light of the fact that language is clearly a cultural construct and that cultural parameters have been shown to influence development and organization. Thus, a direct assumption following from these observations could be that different languages result in different neural structures.

There is clear evidence that cultural parameters present during development and learning, in general, influence the representation of particular cognitive and motor functions in the brain. A number of brain imaging studies have demonstrated reliable differences in brain activation as a function of training and expertise. For example, musicians, highly trained experts in acoustics and mechanical skills related to their specific

instruments, show different brain activations than nonmusicians do when presented with musically related stimuli. Violin players, who depend on the dexterity of the left fingers to produce different notes on the violin, show different activation patterns over somatosensory cortex than nonmusicians do in response to the application of pressure to left digits, but not to right digits (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). Musicians' neurophysiological response was also found to be different when participants were presented with piano (musically relevant) tones versus pure acoustic tones not found in music. This dissociation between different types of acoustic stimuli was not observed in nonmusicians (Pantev, Oostenveld, Engelien, Ross, Roberts, & Hoke, 1998). Musicians and nonmusicians also showed different electrophysiological responses to deviant complex chords based on the saliency of the deviation. Very obvious harmonic disturbances brought on similar event-related brain potential (ERP) components in both groups, whereas less salient errors elicited a modulated response in musicians only (Koelsch, Günter, Friederici, & Schröger, 2000; Koelsch, Schröger, & Tervaniemi, 1999). Such findings suggest that basic parameters of a given cognitive function (in this case, acoustic processing) may be represented in the brain independent of the amount of input or training, whereas higher-level processes (i.e., processing of complex musical stimuli) are not (see Chapter 10).

However, the picture with respect to language may be more complicated because it is not immediately clear exactly what parameters within language might influence the cerebral organization of a speaker's language processing system. On the one hand, languages are clearly cultural constructs and differ substantially in their surface form across cultures. On the other hand, there is a strictly formulated linguistic theory claiming that despite differences in the surface structures of natural languages, the underlying "deep" structure of all human languages is universal, and the acquisition of this universal structure is biologically determined (Chomsky, 1981). Thus, predictions with respect to the possible influence of a particular language on brain structure during learning are not obvious. If surface differences between languages are the relevant parameters influencing cerebral organization of language, one would expect different brain activation patterns as a function of different languages. If, however, the underlying universal structure is the relevant parameter of influence, one would expect similar brain activation patterns for different languages.

Predictions regarding the brain-language/language-brain relationship are complicated not only by the fact that it is not known which language parameters affect cerebral organization, but also by the fact that we do not know whether a normal healthy native speaker of a given language should be considered to be an "expert" of language processing in his or her native tongue. Clearly, there is a large degree of variability in the ability of adults to produce free speech or text. But is a novelist an expert user of language

in the same manner that a violinist is an expert in music? Or is it rather that each healthy native speaker is an expert in his or her mother tongue – at least with respect to everyday language use?

In the following, we review studies that address this problem. Two approaches are taken to highlight the issue under consideration. First, the neural representation of language processes across different languages is compared. In this section, we demonstrate that although languages differ quite dramatically in how they encode lexical and syntactic information, the functional neuroanatomy is rather similar, as are the electrophysiological markers of lexical-semantic and syntactic processes. In the second section, studies are reviewed that directly compare neural representation of two languages in one person. For these studies comparing the processing of the native first language and a nonnative second language, we discuss in detail at what age the second language was acquired, as well as the individual's proficiency, or expertise, in each language. In this chapter, we do not consider issues concerning different writing systems (i.e., the difference between processing phonetically based alphabetic systems, such as in English, versus character-based orthographies, such as in Chinese). Although this topic is certainly interesting, we focus on different spoken languages as the primary issue under consideration because natural spoken languages constitute the primary language system. We make a brief excursion to describe several findings concerning sign language, which also constitutes a natural language, despite its dependency on visual input. Writing systems are considered to be secondary systems from both an evolutionary perspective because they developed long after the spoken languages and from a functional perspective because they cannot exist (as a language) without the spoken language.

Before turning to the different studies in more detail, the brain imaging techniques used in these studies are presented briefly.

METHODS OF BRAIN IMAGING

The brain imaging techniques currently employed to study cognitive functions are restricted with respect to either their temporal or their spatial resolution. Functional magnetic resonance imaging (fMRI) and positron emission tomography measure changes in regional blood flow, aspects that correlate with neural activity. The spatial resolution of today's fMRI with 2 mm is excellent, whereas its temporal resolution with 1 to 3 s is less optimal for time-sensitive processes such as online language use.

Temporal parameters are captured in detail by electroencephalography or magnetoencephalography because these methods register the neural activity online, millisecond by millisecond. The ERP or event-related magnetic field reflects the summation of the synchronous postsynaptic activity of large populations of neurons time locked to critical stimuli. To achieve

a better signal-to-noise ratio for a given event, the brain's activity is averaged over a number of events of the same type. The time-locked average wave forms in the ERP typically display a number of positive and negative peaks after the onset of a given stimulus. The ERP provides three dimensions as defining variables: the latency, measured in milliseconds; the amplitude, which is modified as a function of the difficulty of the cognitive process under investigation; and the topography, which allows for the differentiation of various cognitive processes based on the activation of a variety of neural structures. Here, we should point out that the spatial information provided by ERP's refers to positions over the scalp, and not to specific neural generators. Thus, these latter methods provide an excellent temporal resolution (on the order of milliseconds) but are less optimal in their spatial parameters.

NEURAL REPRESENTATIONS ACROSS DIFFERENT LANGUAGES

More recently, quite a few studies have investigated the neural basis of language processing in healthy participants. These studies have been conducted for different languages, using both fMRI and ERP measures. Clearly, a different pattern of results would be expected for participants under various pathological conditions, such as participants who have undergone hemispherectomy, cochlear implants, or suffered various forms of cerebral insult. However, the way in which specific language components are modulated under such conditions is not the primary topic addressed in this chapter; therefore, we restrict further discussion to findings surrounding healthy participant groups. A second important factor to keep in mind is that a fair degree of variability can be observed even between nonpathological participants performing various language tasks. Interindividual differences are diminished by looking at results obtained from large groups of participants. In the following, we also restrict our discussion to findings pertaining to group studies.

Brain Activation Patterns Across Languages

fMRI language processing studies have been conducted in languages as different as English, Japanese, German, Italian, Hebrew, Dutch, French, and Thai (for recent reviews of fMRI studies and language processing, see Bookheimer, 2002; Cabeza & Nyberg, 2000). Although these studies used different stimulus materials and tasks, common patterns of brain activation have been observed across the different languages. Semantic aspects of processing are supported by the posterior portion of the left superior temporal gyrus (STG) and the middle temporal gyrus, as well as the left inferior frontal gyrus (IFG), in particular, Brodmann's areas (BAs) 45 and 47. Syntactic processes are subserved by the left anterior portion of

the STG and BA 44 in the left IFG. The latter brain area has been discussed as the crucial region involved in the processing of syntactic operations necessary to comprehend noncanonical sentence structures (Grodzinsky, 2000) and syntactic operations of natural languages (as compared with unnatural structures) in general (Musso, Weiller, Kiebel, Müller, Bülaue, & Rijntjes, 2003).

Of crucial interest in a comparison of the underlying brain systems between different languages are those languages that mark the same function by different cues. For example, English marks grammatical function (subject, object) by word order, whereas German can mark it by case (nominative, accusative). However, speakers of both languages rely on the same underlying neural network consisting of superior temporal and inferior frontal regions to parse language stimuli. A more extreme example comes from Thai, which marks lexical-semantic differences by tone (e.g., high low vs. low high) and not necessarily by phonemes as most languages do (e.g., *mouse* vs. *house*). This comparison is quite relevant because prosodic information is known to be processed predominantly in the right hemisphere, whereas phonemic and lexical-semantic information is processed in the left hemisphere (for a review, see Friederici & Alter, 2004). If the coding (tone vs. phoneme) of the information determines the brain activation, one would expect clear differences between Thai and other languages. If, however, brain activation patterns are determined by the linguistic function (lexical-semantic), then one would expect no differences between the languages. A number of brain imaging studies conducted with Thai native speakers (Gandour, Wong, Hsieh, Weinzapfel, Van Lancker, & Hutchins, 2000) indicate that tonal differences are processed in the left hemisphere when they encode lexical-semantic information. Thus, it appears that the function, rather than the encoding parameters, determines the laterality of the brain activation.

Further evidence for the biological determination of different language function comes from studies looking at sign languages. Sign languages provide valuable insights into human language capacities because they represent a natural linguistic form of communication completely dissociated from auditory input. Sign languages are complex, natural human languages that are acquired by children in the same developmental stages as seen for spoken language acquisition (Corina & McBurney, 2001). Despite the clearly different input modalities and types of information used to encode a communicative act in spoken and sign languages, the same brain areas appear to be responsible for processing both language types (Corina & McBurney, 2001; Hickok, Kirk, & Bellugi, 1998). A comprehensive review of individual case studies describing deaf aphasics shows that right-handed signers, like right-handed hearing individuals, exhibit language disturbances only after insult to critical left hemispherical language sites (Corina, 1998; Corina & McBurney, 2001). Furthermore, language

aphasias in sign languages follow the same linguistic patterns observed in aphasias of spoken languages. Thus, comprehension deficits appear to arise after insult to posterior lesions in left temporal cortex, whereas production deficits tend to be the result of lesions in left anterior cortical structures (Corina & McBurney, 2001).

Lateralization of sign language processing has been a matter of debate in recent years. It has been suggested that processing of sign language relies more heavily on right hemispheric structures than does spoken language processing. A recent neuroimaging study comparing activation patterns in deaf and hearing subjects processing both sign and written English language stimuli shows additional involvement of right hemispheric regions when subjects were required to process signs (Neville et al., 1998). The authors suggest that the specific nature and structure of American Sign Language (ASL) lead to this additional recruitment of right hemisphere into the language processing system (but see Hickok, Kirk, & Bellugi, 1998). Specifically, it is proposed that certain linguistic properties (e.g., classifiers) are encoded in ASL in a visuospatial manner not existent in spoken languages (Corina & McBurney, 2001). Such visuospatial information in the language signal could be the cause of additional right hemispheric activation for sign language processing. However, as in the case of Thai, it is assumed that the linguistic information extracted from the incoming signal is further processed by classical language areas (Corina, 1998).

fMRI studies from our own laboratory have directly investigated the processing of comparable linguistic phenomena in German and Russian. In both languages, we investigated lexical-semantic and syntactic processes operationalized in sentences containing a semantic violation or a syntactic phrase structure violation. The semantic violation was realized as a selectional restriction error violating basic semantic features such as animacy (e.g., *The honey was murdered*). The syntactic violation was realized as a word category error within a prepositional phrase; that is, a verb instead of a noun completed the prepositional phrase (e.g., *in the eaten* instead of *in the restaurant*). Sentences with these types of errors were constructed in both German (e.g., semantic violation: *Der Vulkan wurde gegessen* [*The volcano was eaten*]; syntactic violation: *Das Eis wurde im gegessen* [*The ice cream was in the eaten*]) and Russian (semantic violation: *Ja dumaju, shto njebo prokisnjet* [*I think that the sky is sour*]; syntactic violation: *Ja dumaju, shto krjepljenje dlja upadajot* [*I think that the fastening for falls down*]). The study tested a group of German natives ($N = 7$) and a group of Russian native speakers ($N = 7$). The stimulus material contained semantically incorrect sentences, syntactically incorrect sentences, and correct sentences. Participants were asked to listen to the sentences over headphones, and then to judge whether the sentences were well formed and sensible.

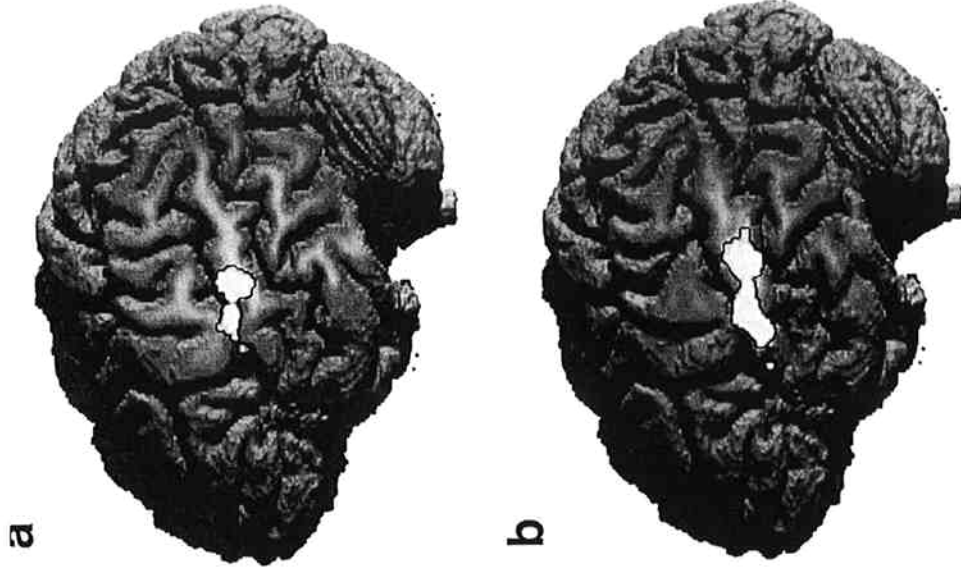


FIGURE 7.1. (a) Increased activation in response to German sentences containing a syntactic violation versus correct sentences in seven German participants ($Z > 2.57$; $p < 0.005$, uncorrected). (b) Increased activation in response to Russian sentences containing a syntactic violation versus correct sentences in seven Russian participants ($Z > 2.57$; $p < 0.005$, uncorrected).

The performance of the two groups indicates that each group is well in control of their native language. The fMRI results demonstrate a high similarity between the two groups. For the syntactic violation as compared with the correct sentences, both groups show increased activation in the left STG, lateral to the Heschl's gyrus and anterior to this (Fig. 7.1).

For the semantic violation condition, increased levels of activation were found in the IFG, namely, within BA 45/47, in both groups (Fig. 7.2). Note

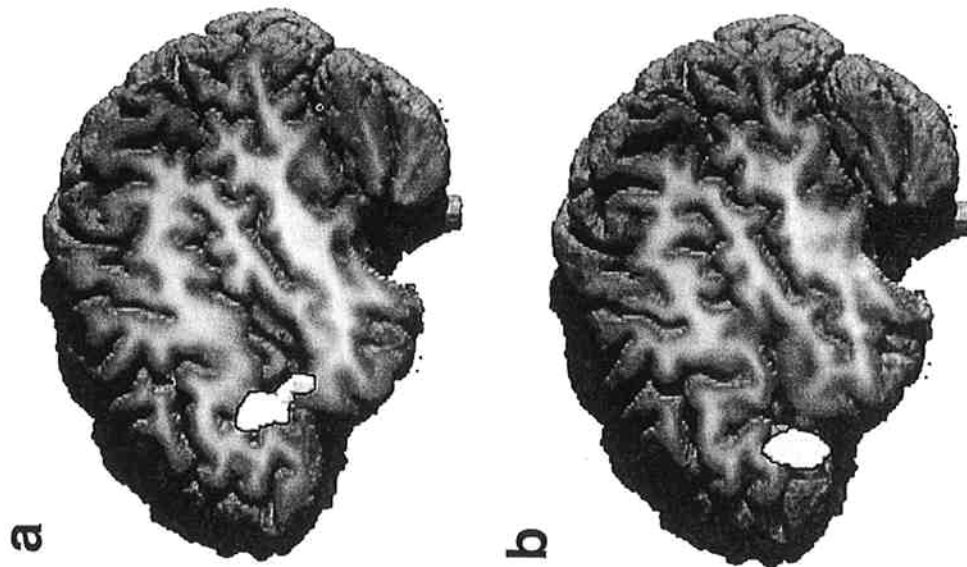


FIGURE 7.2. (a) Increased activation in response to German sentences containing a semantic violation versus correct sentences in seven German participants ($Z > 2.57$; $p < 0.005$, uncorrected). (b) Increased activation in response to Russian sentences containing a semantic violation versus correct sentences in seven Russian participants ($Z > 2.57$; $p < 0.005$, uncorrected).

that the activation locus is not identical in the two groups, but the peaks of activation lie in anatomically comparable areas within the anterior portion of the left IFG.

Thus, the data from the Russian and German natives suggest that the observed brain activation is determined by the linguistic function (semantic vs. syntax) rather than by the language (German vs. Russian).

Again, it should be noted that only a small sample of participants was investigated here ($N = 7$) and that, although the pattern emerging

from these data seems relatively clear, more subtle differences might well become evident with the use of more advanced technology in the future or on investigation of a larger group (see also Rüschemeyer et al., 2005). Furthermore, we make the argument that the observed similarities in brain activation in response to similar linguistic cues is a reflection of identical processes in our two groups of participants. This argumentation is relatively logical and by no means incorrect; however, it is important to keep in mind that the same cerebral areas can be employed for any number of cognitive skills so same brain activation does not always imply same processes. In other words, although it appears that our two participant groups are processing the sentence stimuli in a similar manner, we cannot be absolutely sure on the basis of these data alone that the cognitive processes supported by the observed activations are identical. We feel comfortable, however, in saying that the data are a good indication that two typologically different languages are supported by similar cerebral structures. Although further studies would be necessary to rule out all eventualities, the results from the studies at hand and the current literature seem to support the notion that, in the domain of language, brain activation patterns are not influenced by cultural differences (i.e., by language differences).

LANGUAGE-RELATED ELECTROPHYSIOLOGICAL COMPONENTS ACROSS LANGUAGES

Having seen evidence that the brain activation registered with fMRI is similar across two typologically different languages, one might wonder whether the same holds true for electrophysiological measures. Particular ERP components have been identified as correlates of specific aspects of language processing, such as, for example, semantic and syntactic processing.

The processing of a *semantic* anomaly, measured using ERPs, was first reported by Kutas and Hillyard (1980). They showed that the impossibility of integrating a semantically inappropriate word into a preceding sentence context leads to a negative ERP deflection with a centroparietal distribution present 300 to 500 ms postonset, termed the *N400 component*. The *N400* component was found to correlate in amplitude with the semantic fit between a target word and the restrictions provided by a sentential or word context (Kutas & Hillyard, 1984), and has been supposed to be a marker of semantic integration, in particular (Chwilla, Brown, & Hagoort, 1995).

The *N400* component was first identified in reading experiments (Kutas & Hillyard, 1980), but was also later observed during auditory language processing (Holcomb & Neville, 1990). Moreover, it is important to note that this component is found as a correlate for lexical-semantic processes in a number of different languages, such as English (Holcomb & Neville,

1990; Kutas & Hillyard, 1980), German (Friederici, Pfeifer, & Hahne, 1993), Dutch (Chwilla et al., 1995), French (Radeau, Besson, Fonteneau, & Castro, 1998), Italian (Angrilli et al., 2002), Hebrew (Deutsch & Bentin, 2001), and even for ASL (Neville, Mills, & Lawson, 1992).

As for *syntactic* processing, two components have been identified: an (early) left-anterior negativity (which is termed *ELAN* or *LAN*, depending on latency) and a late centroparietal positivity (referred to as the *P600* component).

Left anterior negativities with a maximum latency below 200 ms have been found to occur with phrase structure violations in English (Neville, Nicol, Barss, Forster, & Garrett, 1991) and German (Friederici et al., 1993) and have been termed *early left anterior negativity (ELAN)*. The finding that this component varies with probability (Hahne & Friederici, 1999) indicates that it reflects highly automatic processes. There is some evidence that the *ELAN* is dependent on input parameters because it did not show up consistently in studies also employing visual word-by-word presentation and because its latency has been shown to depend on visual contrast (Gunter, Friederici, & Hahne, 1999). *Left anterior negativity (LAN)* effects, between 300 and 500 ms, follow violations based on syntactic information other than word category, such as different types of agreement phenomena (in Dutch: Gunter, Stowe, & Mulder, 1997; in German: Münte, Matzke, & Johannes, 1997; in Italian: Angrilli et al., 2002; and in Hebrew: Deutsch & Bentin, 2001).

The *P600 component* is a positive deflection in the ERP that develops from 500 ms onward and has a centroparietal maximum around 600 ms. It has been found for ungrammatical sentences such as phrase structure violations, verb-argument structure and subcategorization violations (in English: Coulson, King & Kutas, 1998; in German: Friederici & Frisch, 2000), subadjacency violations (in English: Neville et al., 1991), agreement violations (in Dutch: Gunter et al., 1997), and for nonpreferred disambiguation of ambiguous sentences (in English: Osterhout & Holcomb, 1992; in German: Frisch, Schlesewsky, Saddy, & Alpermann, 2002). In recent studies, it is more generally conceived of as a marker for syntactic integration cost (Kaan, Harris, Gibson, & Holcomb, 2000).

In the syntactic domain, there are, however, some reports that point to a divergence of syntactic ERP effects between different languages. Because most of the ERP studies on syntactic processing have been conducted in English, Dutch, and German, the available data are limited. Moreover, the crucial studies differ with respect to the speed of input because some studies presented the stimulus material auditorily as connected speech and some visually in a word-by-word manner. It has been shown that this aspect affects the *ELAN*, even within one language, for the same sentence material (Gunter et al., 1999). Moreover, visual word by word also appears to affect the presence of the *LAN* effect during agreement processes in

English (Osterhout & Mobley, 1995) and in Dutch (Hagoort, Brown, & Groothusen, 1993). Because the *LAN* is sometimes observed in these languages (in Dutch: Gunter et al., 1997; in English: Coulson et al., 1998) and is sometimes not (in Dutch: Hagoort et al., 1993; in English: Osterhout & Mobley, 1995), the absence of the *LAN* in these studies cannot be taken to reflect language-specific differences.

Another crucial consideration is to what extent differences between languages are reflected in the ERPs. Take, for example, the obvious difference between languages with relatively strict word order (e.g., English and Dutch) and those with relatively free word order (e.g., German, Russian, Japanese). In the latter languages, grammatical relations between the arguments in a sentence can be marked by means of case. Thus, various processes may be applied in these different languages during sentence processing to build up grammatical relations. Whereas word order-based processes are most relevant during online comprehension of English sentences, case information-based processes are applicable for German, Russian, and Japanese. A recent model of language comprehension has captured this processing difference by assuming two processing streams for the assignment of grammatical relations and thematic roles in the human parsing system (Borckesell, 2002).

The activation of each of these two processing streams is assumed to be a function of the type of information (word order vs. case information) in a given language. ERP experiments with German sentences containing unambiguous case marking have shown that incorrect case marking can lead to an N400 effect in German (Frisch & Schlesewsky, 2001) and to a *LAN* effect in English (Coulson et al., 1998). This difference is predicted by the model cited previously in that it assumes that when unambiguous case information is available, the system assigns the thematic/semantic role immediately on the basis of this information. For example, an argument marked in the nominative case is most likely to correspond to the actor in the sentence. A violation of expected case information (e.g., two arguments marked nominative in one sentence) makes the assignment of thematic/semantic roles impossible and therefore leads to an N400 as shown by Frisch and Schlesewsky (2001). In English, no such direct mapping is possible because grammatical relations are indicated by position. Thus, in a sentence such as *The plan took me to paradise*, the parsing system detects that the word "we" signaling subjecthood is in the incorrect position, and the brain elicits an *LAN*, a syntactic ERP component (Coulson et al., 1998). Thus, it appears that violation of case marking evokes different ERP components, depending on whether the language provides the possibility for direct mapping from case information to thematic roles.

When these data are considered with respect to the issue of biologically constrained universality of the neural basis of language processing versus the notion of a culturally determined brain basis, the data reviewed