

Brain and Language Specialty: Insights from Aphasiology and Neuroimaging

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Abstract—Scientific interest in the investigation of language and its neural correlates has always centered on the possibility of pinpointing the location of language in the brain with the assumption that specific areas of the brain could be dedicated to specific language components and processes. A central question in current neurolinguistic and psycholinguistic research that has been thoroughly discussed over the last few decades is whether certain linguistic abilities result from dedicated brain areas each specialized for specific kinds of linguistic representations and processes or whether these abilities are more accurately described in terms of interactions among different linguistic levels distributed across multiple brain regions. An outlook on language derived from current research suggests that language specialty as a distinctly human cognitive faculty lies in being supported by distributed neural structures that interact efficiently with so many domain-general abilities, functions, and information sources rather than in being located in a dedicated set of cognitive neural structures. This paper is a reflection of the insights into language in the brain based on findings obtained from neuropsychological and neuroimaging studies that support this perspective. The paper goes on to plead that with current developments in linguistic theory, as a model of human knowledge of language, and some powerful methodological advances in cognitive neuroscience may lead to a new and more precise image of the functional organization of language in the brain.

Index Terms—localization, modularity, neuroimaging, Broca's area, language networks

I. INTRODUCTION

One of the most challenging issues related to human language is understanding how it is organized and processed in the brain (Blumstein, 1995). Prior to the onset of functional imaging techniques (Petersen *et al.*, 1989), most findings concerning the representation of language in the human cerebral cortex were derived from neuropsychological investigation of language pathology subsequent to brain damage or by electrical stimulation and recording from individuals undergoing neurosurgery (Horwitz & Wise, 2008). Data from the application of deficit-lesion correlations provided important findings regarding the neural organization of language functions. Neuroimaging studies of cognitive function have looked to lesion studies for confirmation of the functional organization of the brain. The advances in neuroimaging methods have provided researchers with a powerful, noninvasive means to examine brain activity during processing of linguistic stimuli. This activity can be measured while people read or listen to sets of words or sentences with ERPs (Event-Related Potentials), PET (Positron Emission Tomography) scans, and fMRI (functional Magnetic Resonance Imaging) scans. The new findings supported by modern neuroimaging techniques have challenged the classical view regarding language and its underlying neural organization, and has lent support to a new perspective on cognitive functions as being mediated by distributed interacting neural elements (Horwitz & Wise, 2008).

There are currently two main prominent views about the study of the neural representation of language functions: the modular account suggests that brain regions are specialized for particular language functions, while the distributive account claims that language requires cooperation of widely distributed brain regions. Researchers following the modularity perspective have assumed a set of distinct processing components within a modular system, each subserving a language-specific function and operating on language-specific information and representations (e.g., Fodor, 1983; Fromkin, 1997; Pinker, 1994; Pinker & Ullman, 2002). Such proposals assume a static base of linguistic knowledge, which is associated with distinct neural structures. The origins of these claims lie in Franz Gall (1809) who conceived of the brain as composed of several independent organs, each subserving a specific faculty (cf. Trimble, 2007).

Conversely, the distributive or connectionist perspectives of brain function emphasize circuits, parallel processing, and the cortical-subcortical representations of functions (e.g., McClelland & Rumelhart, 1986; Seidenberg & McClelland, 1989). According to the current connectionist model, individual concepts are represented by a pattern of activation existing across a large network of interconnected nodes; the nodes and connections are argued to be analogous to neurons and their synaptic connections (see, for example, Pulvermüller, 2003). As a result, language processes should engage multiple distributed brain areas, which may be involved in a variety of cognitive functions that are not specific to language.

Current research in neurolinguistics uses the available methods, approaches and powerful new technologies to investigate brain structure and function with respect to language representation through addressing three basic questions: (1) What are the neural underpinnings of language? (2) Are these neural correlates exclusively dedicated to language? (3) How is language represented in the human cerebral cortex? The major objective of the present paper thus is to

survey this new literature, focusing on findings from neuropsychological and neuroimaging studies that examined the neurological and functional organization of language in the human cerebral cortex. The paper is organized as follows. First, we present a brief overview of the brain regions commonly known to be involved in language processing. We then review and discuss the neural and functional organization of language, with reference to neuropsychological and contemporary neuroimaging studies. In this section, we focus on the implications of the findings of these studies on the evidence for the modular versus the distributed nature of the neural substrate for language functions. We then briefly discuss the role of Broca's area in language processing, based on data from recent neuropsychological and brain imaging studies. We close by presenting some concluding remarks on the implications of current research for the nature of language representation and processing in the human brain and current limitations and future directions of research on the relationship between language and the brain. We begin by introducing the brain regions commonly known to be involved in language processing.

II. BRAIN REGIONS INVOLVED IN LANGUAGE

The part of the brain most relevant for language is the cerebral cortex (Pulvermüller, 2002). This fact has been proved by neurological observations where lesions in certain regions of the cortex lead to neurological language impairment known as aphasia (Broca, 1861/1977). Current neuropsychological research on the neural structures of language has resulted in confirming that human language involves parts of the association cortex in the lateral portion of one cerebral hemisphere, usually the left in right-handed individuals. The cortex includes the Sylvian fissure and runs from the pars triangularis and opercularis of the inferior frontal gyrus (Brodmann's area (BA) 45 and 44; Broca's area) through the angular and supramarginal gyri (BA 39 and 40) and into the superior temporal gyrus (BA 22; Wernicke's area) (Caplan, 2009). Broca and Wernicke regions are crucial for language. As we shall see, however, the involvement of each area in particular components of language processing is still unknown. Figure (1) shows a lateral view of the left hemisphere with its most common area subdivision.

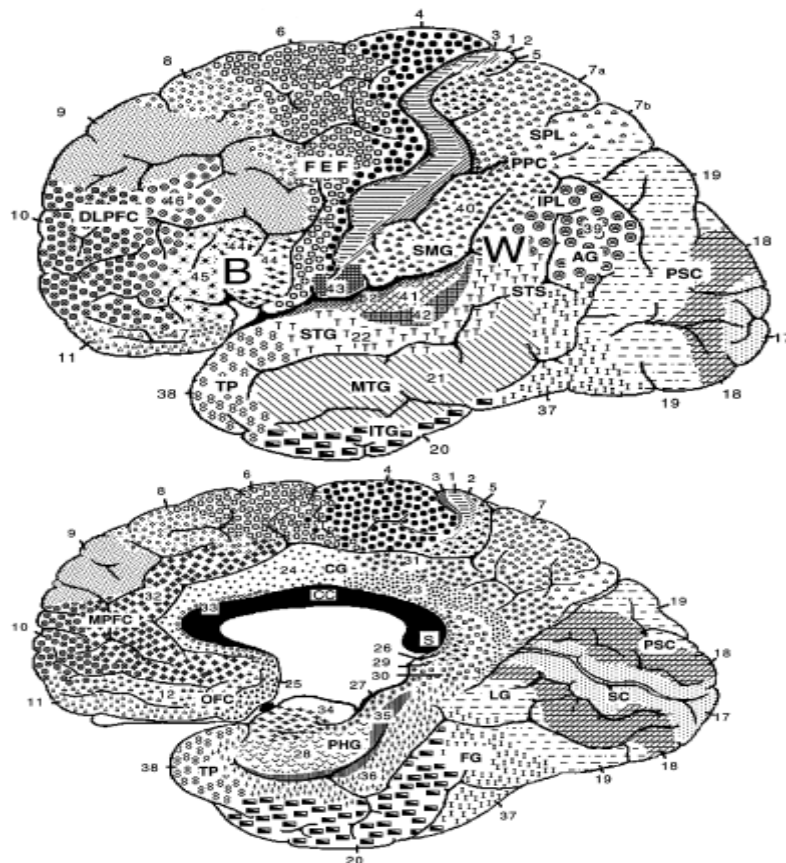


Figure 1: A representation of the cortical map of Brodmann, which distinguishes regions of the cortex on the basis of their microscopic features. AG, angular gyrus; B, Broca's area; CC, corpus callosum; CG, cingulate cortex; DLPFC, dorsolateral prefrontal cortex; FEF, frontal eye fields (premotor cortex); FG, fusiform gyrus; IPL, inferior parietal lobule; ITG, inferior temporal gyrus; LG, lingual gyrus; MPFC, medial prefrontal cortex; MTG, middle temporal gyrus; OFC, orbitofrontal cortex; PHG, parahippocampal gyrus; PPC, posterior parietal cortex; PSC, peristriate cortex; SC, striate cortex; SMG, supramarginal gyrus; SPL, superior parietal lobule; STG, superior temporal gyrus; STS, superior temporal sulcus; TP, temporopolar cortex; W, Wernicke's area. Adapted from Mesulam (2002).

Findings from imaging studies of the brain areas involved in language processing have confirmed the involvement of the main regions of perisylvian cortex known as Broca's area and Wernicke's area identified as the primary language

areas on the basis of neuropsychological findings from aphasia studies. Both areas appear to be necessary for language processing, even though neither of them is sufficient for word comprehension or production (Indefrey, 2007). A crucially important finding from such research has been that many other cortical and subcortical areas outside the perisylvian language cortex are actively engaged in language processing as well. These structures are not restricted to the language-dominant left hemisphere, but include areas in the nondominant right hemisphere as well. The role of subcortical structures in language processing is much less understood than cortical structures, but recent evidence links them closely to cortical mechanisms of language. Some of these structures comprise "the middle and interior regions of the temporal lobe for its role in word-level processes, the anterior superior temporal gyrus (STG) for its role in the construction of phrases as well as intelligibility, and subcortical structures (basal ganglia and cerebellum) for their role in linguistic computation" Poeppel & Hickok, 2004:9). Recent functional imaging techniques have also revealed the involvement of the premotor cortex in language processing (e.g., Wilson *et al.*, 2004). In addition, the insula, a large limbic lobe structure, has been found involved in many functions including integration of limbic and cortical information; it also links anteriorly with the frontal cortex (Trimble, 2007).

The basal ganglia and the thalamus (figure 2) are subcortical structures that have received the most attention in studies of language processing and subcortical aphasia (Cappa & Abutalebi, 1999; Friederici, 2006). As reviewed by Kertesz and Wallesch (1993), the basal ganglia are essential relay systems between subcortical and cortical structures. The basal ganglia are a collection of structures consisting of the striatum, the globus pallidus, and the thalamus. The thalamus is the most medial of the nuclei of the basal ganglia, and occupies the two sides of the third ventricle. Recent evidence has established the involvement of these subcortical structures in aspects of language processing. For example, the basal ganglia has been suggested to be involved in 'rule-based' processing in language, such as regular aspects of word formation, while the thalamus appears to play a role in processing the meanings of words (Caplan, 2009).

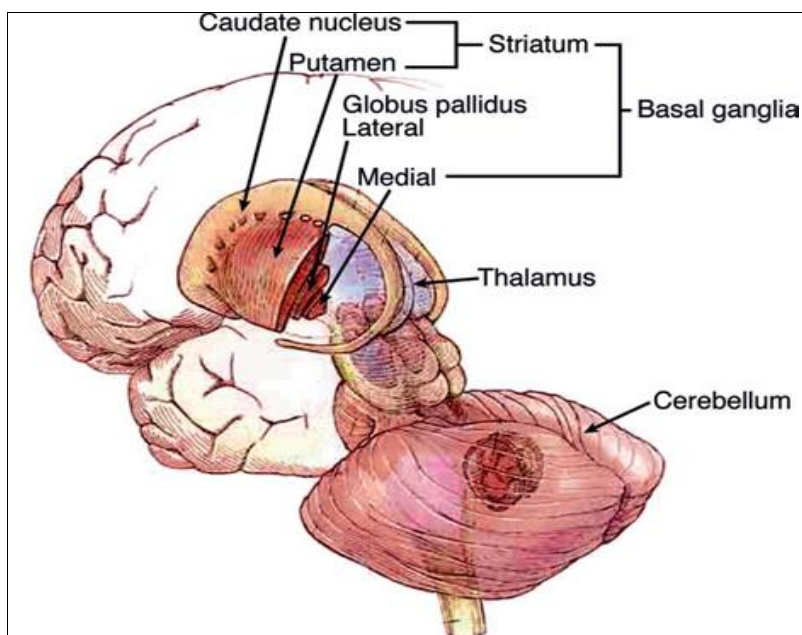


Figure 2: The location of subcortical regions involved in language processing. The insula, a cortical region located deep to the brain's lateral surface at the junction between the frontal, temporal, and parietal lobes, is not visible in this figure. Adapted from Bornkessel-Schlesewsky & Schlesewsky (2009).

III. THE NEURAL ORGANIZATION OF LANGUAGE

Despite the fact that scientific inquiry into brain-language relationship has grown considerably to support the neural basis of language, the issue of how human brain supports language is still not clearly understood. Moreover, as part of this incomplete knowledge, the relationship between cortical brain areas involved in language processing is less well known compared to many other brain functions. Amunts (2008) attributes this difference to the fact that human language is very complex in comparison to other cognitive functions, and the disagreement among researchers as to how this function should be analyzed and be related to the underlying anatomy. The debates today mostly concern "whether there are domain-specific modules associated with different components of the grammar, whether such modules recruit distinct neural structures that are solely dedicated to the processing of that module and whether the neural systems associated with language are different from those recruited across other cognitive domains" (Blumstein & Amso, 2013:45; as quoted in Cahana-Amityay & Albert, 2014 :3). We address these issues in the following sections.

A. Evidence from Lesion Studies

The classical lesion-deficit model developed in the late 1800s by Wernicke, Broca, and Lichtheim and revived by Norman Geschwind (1970) constitutes the standard model that has guided research for almost a century and a half, and its goal is to formulate typologies of language disturbance, using structure-function correlations (Siddis, 2006). Current research has revealed a number of inconsistencies that, on the one hand, refute such a rigid locationist theory and, on the other hand, provide significant insights into the nature of language representation in the brain. We focus here particularly on the following controversies discussed under the following subsections

1. The localization issue: structure-function correlation principle

Research on the neural organization of language based on the classical lesion-deficit model developed in the late 1800s by Wernicke, Broca, and Lichtheim and revived by Norman Geschwind (1970) has accentuated belief in the existence of cerebral language centers primarily localized in the left hemisphere. Research of aphasic patients resulted in a general model for mapping language functions to relatively specific regions of the left hemisphere (Carter, 1998). Thus, for example, two large brain regions, Broca's area in the left posterior inferior frontal gyrus (IFG) and Wernicke's area in the left posterior superior temporal gyrus (STG), were linked to language functions. This claim led researchers to speculate that language is actually embodied in the wiring of these areas of the brain, i.e., Broca's area as closely related to speech production while Wernicke's area as associated with speech comprehension. As we shall see, however, this view of brain-language mappings has been challenged on empirical reasons.

First, the basic assumption of lesion studies is that the symptoms of aphasia are related in a straightforward way to anatomical lesions. As Kertesz and Wallesch (1993: 132) states "One can only localize lesions (and accompanying physio-logical and metabolic changes) associated with certain behavioural alterations but not function". Moreover, the relationship between a particular language function and specific brain region is significantly more complex and more variable. For instance, lesions in the frontal and temporal lobes, some of which spared the perisylvian language areas, lead to impairment in producing or understanding words (e.g., Damasio & Tranel, 1993; Humphreys & Forde, 2001). In addition, lesions around the inferior frontal gyrus correlate with different aphasic symptoms within Broca's aphasia (Alexander, Naeser & Palumbo, 1990). This suggests that other areas outside the classical language areas are crucial for language processing. Conversely, a lesion to a certain area does not necessarily lead to a predictable language breakdown. For instance, neither lesions to Broca's area lead to a persisting Broca's aphasia, nor do lesions affecting only Wernicke's area lead to a persisting Wernicke's aphasia (Mohr *et al.*, 1978; Dronkers, Redfern, & Knight, 2000). Such findings reveal the limit of aphasiology studies by suggesting that a wide range of cortical and subcortical regions are associated with language processing.

Second, findings from imaging studies in normal and language-impaired individuals make strong claim against the view that language is represented in specific cortical regions of the brain, i.e., Broca's area as closely related to speech production while Wernicke's area as associated with speech comprehension. For example, patients with Wernicke aphasia have difficulty speaking, even if their lesion is restricted to the superior temporal lobe (Pulvermüller *et al.*, 1996). Similarly, patients with Broca aphasia have specific comprehension deficits with certain types of sentences such as passive sentences (Caramazza & Zurif, 1976). Thus, the specific function of the inferior frontal area of Broca and the superior temporal area of Wernicke as centers contributing to either speech production or comprehension has been questioned. Recent imaging studies confirm that both classical language areas central for language processing in the cortex appear to be functionally interdependent (e.g., Hickok and Poeppel, 2000; Bornkessel-Schlesewsky and Friederici, 2007; Indefrey, 2007).

Finally, there is increasing evidence that for some cognitive functions, alternative brain systems might be available, and one area within association cortex might be a node in different functional networks. Consequently, the absence of a cognitive deficit after a lesion to a specific brain area does not necessarily entail that the lesion area is not involved in the spared function (Hagoort, 2006). Moreover, imaging studies, as we shall discuss in the coming sections, clearly show that mapping deficits to lesions does not imply the existence of a specialized area that is dedicated exclusively to a particular function or cognitive process.

These considerations have provided compelling evidence against the classical view regarding the brain centers, and led researchers to consider the importance of brain regions other than the classical language cortex in normal language and aphasia (cf. Bookheimer 2002; Brown & Hagoort, 1999; Metter 1995; Patterson & Bly 1999; Poeppel & Hickok 2004). As a result, a new perspective on the involvement of the whole brain in language processes has begun to emerge.

2. The modularity hypothesis: language domain-specificity

The proposal that the human mind is composed of faculties or modules realized in specific neural structures is central to the work of the nineteenth-century neurologists. Current modular views represent a further development of the localizationist perspective with the assumption that language is relatively independent from other cognitive processes and is mediated by distinct neural structures (see, for example, Fodor, 1983; Pinker, 1999). According to this view, the brain consists of modules each specified for different functions such as informational encapsulation, domain specificity, and a dedicated neural location.

Dissociations have been found between language and other cognitive processes; it has been observed that language can be seriously disrupted in the presence of spared cognitive processes and vice versa (cf. Bellugi, *et al.*, 1993). The main evidence in favor of the modularity hypothesis or the domain-specificity of the language faculty comes from neuropsychology. Selective language deficits have also been found in aphasics where other language abilities are

relatively spared. This has been cited as evidence in favor of linguistic modularity (Fromkin, 1997; Pinker, 1994). In general, language impairments in aphasia seem to support the view of language modularity, which is functionally and neurologically distinct from other higher cortical functions (see Blumstein, 1995; Dąbrowska, 2004, for discussion).

A prominent assumption that has dominated theoretical discussions of the modularity is the separation between lexical and grammatical processing observed in certain aphasic patients (e.g., Pinker & Ullman, 1994). The classical distinction between Broca and Wernicke's aphasia would appear to provide compelling evidence for these claims. According to the traditional characterization of these disorders, patients with Broca's aphasia due to damage to left inferior frontal brain regions experience a loss or disruption of grammatical rules resulting in a deficit in syntactic comprehension. Conversely, patients with Wernicke's aphasia due to damage to left posterior temporal brain regions experience a loss or disruption in lexical-semantic representations resulting in a deficit in semantic comprehension (Ullman, 2001). This apparent double dissociation has been used to argue for supposing the existence of functionally specialized neural modules for lexical and grammatical representations.

Investigation of the nature of language impairments in aphasia reveals that the dissociation between production and comprehension or grammar and the lexicon is not as specific as has been previously suggested, and in fact may be more easily accounted for in terms of a general processing model. For example, Bates and Goodman (1997) argue that language impairment in aphasia do not provide convincing evidence of the dissociation between grammar and the lexicon, leading them to reject the view that these functions are mediated by domain-specific neural systems. More recently, Aydelott, kutas and Federmeier (2005) present evidence from some neurophysiological studies demonstrating that language comprehension is subserved by a distributed processing network involving multiple brain areas in both the left and right hemispheres, with no clear distinction between perceptual and conceptual processing. The results presented also demonstrate that the neural mechanisms involved in language comprehension are also responsible for the processing of other kinds of information, including the recognition of visual objects, with no evidence for a distinct language neural system.

Another issue that has tended to dominate theoretical discussions of modularity concerns the separation of distinct components of the grammar. Under this strong version of the modularity hypothesis, it has been assumed that language consists of submodules, which are functionally autonomous, with a restricted domain of analysis and processing (e.g., Fodor, 1983; Garrett, 1979). Selective syntactic deficits have been found in aphasic patients where other language abilities are relatively spared (e.g., Berndt & Caramazza, 1980; Caramazza & Zurif, 1976). This has been cited as evidence that the human brain contains an autonomous faculty or module dedicated exclusively to the representation and/or processing of syntax (Grodzinsky, 1995, 2000; Pinker, 1994).

The results of several studies of aphasia suggest that there is little evidence to support the view that the organization of the language system itself is modular (Blumstein, 1995). In particular, it has been found that there is no systematic correlation between a specific brain lesion and the presence of syntactic comprehension deficits (e.g., Caplan, Hildebrandt, & Makris, 1996; Dick *et al.*, 2001). Grammatical functions are also impaired in Wernicke's aphasia (Caplan *et al.*, 2004), and phonology is seen as distorted in the non-fluent as well as the fluent aphasias (Levy & Kavé 1999). Language impairments in aphasia thus are not selective with respect to a particular component of the grammar nor do they reflect impairments to particular linguistic representations (Blumstein, 1995). Moreover, aphasic patients' deficits are argued not to reflect damage to specific language modules but rather processing impairments. This interpretation appears to be supported by several studies which show that neurologically intact individuals can be shown to exhibit patterns of linguistic impairment that mirror the various dissociations observed in aphasic patients when required to process spoken utterances under conditions of perceptual and cognitive stress (Dick *et al.*, 2001). This fact has been taken to support a distributive model of language in the brain, where language functions are distributed over several cooperating areas, rather than having any specific locus (Dick *et al.*, 2005).

In addition to the neuropsychological evidence against the modularity view, the issue of language resilience provides another evidence against the modularity perspective of language. There is considerable evidence that cortical tissue is quite plastic in that it can support different representations (Elman *et al.*, 1996). In particular, studies on children with early focal lesions and hemispherectomy tend not to show consistent differences between early left and right hemisphere injury in terms of language abilities (Dick *et al.*, 2005). Although these children show language processing delays in comparison with their age-matched peers, they show remarkably spared comprehension and production relative to adults with comparable focal lesions. This suggests, as proposed by Leech & Dick (2009), that the brain has some flexibility to reorganize such cognitive functions in children with early focal lesions and thus enables them to acquire normal language. These findings lend further evidence against the notion that language functions are localized within specific left hemisphere regions (cf. Leech & Dick, 2009).

Finally, under the modularity hypothesis, the assumption that language consists of submodules or components, such as phonological, syntactic, and semantic, which are functionally autonomous, is controversial. For example, most of linguistic theory posits a delimitation between syntax and semantics for language analysis purposes, but which in actual practice does not exist (Sidtis, 2006). These two "levels" commune and interact and signal each other incessantly (Bates & Goodman, 1997; noted in Sidtis, 2006). Further, their status as autonomous components in mental and cerebral processing is not recognized. Geschwind (1974) notes, we cannot expect every nameable feature; e.g., each theoretical

linguistic component, to correspond in some obvious way to a particular cortical location. As suggested by Finlay (2005:2006):

...cortical areas are not particularly important features of cortical organization, and most certainly do not correspond to "modules"—localized regions that do a distinct input-output computation and are functionally isolated. Rather, they are epiphenomena of a particular way of maximally specifying and fanning out information from thalamus to cortex, while allowing intracortical projections to recombine this distributed input quite widely and use prior activity (memory) and other current activity to recognize emerging patterns across this matrix.

Therefore, as will be discussed in the next section, it is unlikely that the components of language have a direct instantiation in localized areas of the brain.

B. Evidence from Brain Imaging Studies of Language Processing

From a linguistic viewpoint, it has been argued that the language components such as phonology, syntax, and semantics might yield a clearer picture of the neurology of language. However, the complexity of neural activation when the brain is engaged in simple language processing tasks as well as the complex nature of the interactions between phonology, semantics, and syntax poses a challenge to the study of these individual processes in language processing. These difficulties have played a significant role in modern functional neuroimaging techniques. Thus, much of the current research has focused on the possibility of identifying specific neurocognitive correlates of the processing of distinct language components. Both PET and fMRI have been extremely useful for identifying brain regions activated during processing of linguistic stimuli. In this section, we consider the extent to which neuroimaging data is reconcilable with this viewpoint.

1. Phonetic/phonological processing

Traditionally, anterior aphasias with frontal lobe lesions in Brodmann's areas (BA) 44 and 45 have been associated with phonological disturbances. Both anterior and posterior aphasias show disturbances in phonological aspects of language input and output (Caplan, 1992). As reviewed by Shafer and Garrido-Nag (2007), studies of speech perception show that primary auditory cortex (BA 41) and secondary auditory cortex (BA 42) are involved in speech perception. Different portions of these regions are activated in different types of processing. Activation in the bilateral superior temporal gyrus (STG) is observed for pre-lexical processing of phonetic features. The left posterior superior temporal sulcus (STS) shows particular activation for phonetic features and the right STG to melodic variation of speech. Mapping of speech onto lexical-semantic representations activates the left anterior portion of the STS (BA 22). An additional cortical area of activation has been described in the planum temporale (PT), part of Wernicke's area in posterior superior temporal cortex, which serves as a motor/sensory interface for any acoustic stimulus. Taken together, neuroimaging studies have shown that phonological processing involves posterior brain regions of the superior temporal gyrus (BA 41, 42, 22) for speech perception, and PT for interfacing with the motor system. It also has been suggested that left prefrontal cortex (BA 44/6) is activated in processing rapid transitions, such as those found in consonant-vowel syllables, and in accessing, sequencing, and monitoring phonemes (see figure 3).

2. Semantic/discourse processing

Wernicke's area is traditionally associated with semantic and discourse processing. Recent neuroimaging studies, as reviewed by Shafer and Garrido-Nag (2007), have shown that widespread anterior and posterior cortical regions are involved in semantic processing. Activation of the pars orbitalis of the left inferior frontal gyrus has also been observed while processing semantic relationships and/or retrieving semantic information, whereas the left superior temporal sulcus (posterior cortex) is activated in mapping between speech and lexical-semantic representations. In addition, activation of right cortical regions has been observed in pragmatic/discourse and prosodic functions, such as interpreting metaphors and morals, creating coherence, topic maintenance, and using prosody to interpret emotion. For example, BA 44/45, dorsolateral prefrontal cortex (BA 46), superior temporal cortex (BA 22), and angular gyrus (BA 39) are highly activated in topic maintenance. Findings from neuroimaging studies thus show that semantic/discourse processing is broadly distributed in both anterior and posterior regions of the left hemisphere, with right hemisphere activation commonly observed in pragmatic/discourse processing.

3. Syntactic/morphosyntactic processing

Neuropsychological studies associate damage to the left inferior frontal regions (BA 44 and 45) with syntactic and morphological deficits (Miceli & Caramazza, 1988). Brain imaging studies show that the pars opercularis in the left third frontal convolution, i.e. in and around Broca's area, is associated with syntactic processing (Caplan, Alpert, & Waters, 1998; Ni *et al.*, 2000; Stromswold, *et al.*, 1996). Recently, however, the role of Broca's area in syntactic processing has been challenged. According to Kaan and Swaab (2002: 355), neuroimaging findings suggest that "syntactic processing recruits not one brain region but multiple areas that are not each uniquely involved in syntactic tasks." It has been proposed that different parts of the brain may be involved in different aspects of syntactic processing, such as encoding, storage, and lexical processing (Kaan & Stowe, 2002; Keller, Carpenter, & Just, 2001; Stromswold *et al.*, 1996). In a recent study, Moro (2008) proposes that Broca's area is selectively involved for syntax within a complex net that also involves the activation of subcortical portions of the brain. It is its interaction with the caudate nucleus that constitutes a network that is specifically involved in syntax.

As far as morphosyntactic processing is concerned, imaging studies show that regions in left prefrontal cortex are involved in processing of morphosyntactic information (see figure 3). In particular, the premotor cortex (BA 6), pars

opercularis, and putamen (basal ganglia structure) are activated in learning and recognizing simple grammars with phonological encoding, and pars opercularis and triangularis (BA 44/45) are activated in recognizing higher-level grammatical patterns. In posterior cortical regions, the anterior portion of the left superior temporal gyrus is also activated in processing morphosyntactic information (Friederici, *et. al*, 2003). Generally speaking, imaging and neurophysiological studies indicate that left anterior regions, including Broca's area and basal ganglia subcortical structures, are highly activated in early and late aspects of morphosyntactic processing (for a review, see Shafer and Garrido-Nag, 2007).

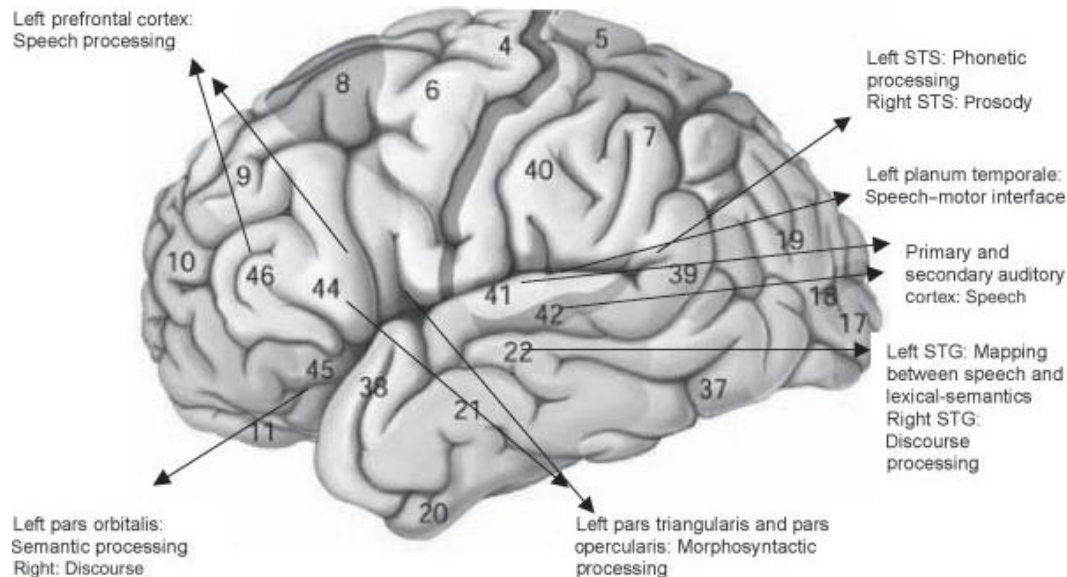


Figure 3: Brain structure-language function relationships. Brain regions typically activated during (1) phonetic/phonological processing related specifically to speech perception, (2) morphosyntactic processing, and (3) semantic/discourse processing. Adapted from Shafer and Garrido-Nag (2007).

In spite of indisputable correlations between particular language components and certain neurocognitive processing domains, many recent studies argue against the one-to-one mapping principle between cognitive functions and the activations of a single area. For instance, Bub (2000: 468; as quoted in Beaton, 2004: 235) convincingly argues that one should not be attracted by “the hidden tendency to assume that the pattern of activation seen in the final image is a literal description of neurons firing to a particular task demand.” Beaton (2004) further elaborates that lack of PET activation does not mean lack of brain activity. Thus, the patterns of activation reported in published papers do not necessarily identify those neural areas involved in a given task. Moreover, to claim a critical role of cortical structures in language processing does not mean that they are uniquely dedicated to language functions (Saygin, *et al.*, 2003). This implies that the appearance of a particular processing effect is not necessarily to claim domain specificity for that area. On the other hand, many of the elements of the neural net underlying different aspects of language are also involved in the performance of other cognitive tasks (Kaan & Swaab, 2002), in interaction with other brain regions (Heim, Opitz, & Friederici, 2003). On this view, a particular cognitive function is most likely served by a wide range of cortical areas, rather than by one local area alone. In addition, a local area participates in more than one function and thus challenges the notion that language-related areas subservise language-related functions only. Consequently, “although it is theoretically possible that there is a well-defined cortical (or other) region of the brain corresponding to the theoretical linguist’s “syntactic component,” it is just as possible in theory that such a component corresponds to the intersection of several such regions, or even to no anatomically well-defined region, but rather results from the complex interaction of diverse neural circuits” (Jenkins, 2000: 65). However, this does not mean that different areas of cortex are not specialized for different components of the language processing system. It only means that the one-to-one mapping principle between a single anatomical region and a particular cognitive process and vice versa is in many cases not an adequate account of how cognitive functions are neurally instantiated (cf. Hagoort, 2006; Moro, 2008).

In sum, findings from brain imaging studies suggest that language processing activates a complex neural network of primarily left fronto-temporal brain regions in concert with a number of other areas such as the basal ganglia (Bornkessel-Schlesewsky & Schlewsky, 2009). The two most directly involved areas of this Perisylvian network are an inferior frontal region and a superior temporal region, (Broca and Wernicke’s areas respectively). These two areas are connected with each other as well as with multiple regions of the temporal, parietal, and frontal lobes (Mesulam, 2010). The precise role of Broca’s area in language functioning has been questioned as will be highlighted in the next section.

IV. BROCA’S AREA AND LANGUAGE SPECIFICITY: A MULTIFUNCTIONALITY PERSPECTIVE

Since the influential work of the French neurologist Paul Broca (1861), Broca's area has represented one of the most challenging areas of the human brain. A preoccupation of aphasia research has been the role of Broca's area in language. Broca's claim recognized that the posterior part of the left Inferior Frontal Gyrus (IFG) was of critical importance for speech production. Many functional imaging studies support this claim. For example, studies have shown the involvement of inferior frontal cortex in language production (Kim *et al.*, 1997; Petersen *et al.*, 1988), and in syntactic as well as phonological processing (Friederici *et al.*, 2003). Recent neuroimaging and neuropsychological studies challenge the specificity of the role of Broca's area for language processing and suggest that Broca's area or parts of (Brodmann's area 44) subserve other cognitive functions in addition to speech and hence may be part of human inferior premotor cortex (Binkofski and Buccino, 2004). For instance, several recent experiments have shown that Broca's area seems to be involved in the processing of musical sequences (Koelsch *et al.*, 2000; Patel, 2003), the imagination of movement (Binkofski *et al.*, 2000) and the perception of the rhythm of movement (Schubotz & von Cramon, 2003). It has also been observed that listening to complex music and mentally rehearsing music activates much the same areas as language, i.e. both Broca's and Wernicke's (Hickok *et al.*, 2003; as noted in Stowe, Haverkort & Zwarts (2005)

In addition, Broca's area may play some role in language comprehension. This assumption seems to be supported by several studies showing that Broca's aphasics, in addition to their deficits in production, are also impaired in speech comprehension. Deficits are more evident when patients were tested with verbal material requiring syntactical understanding (Caramazza and Zurif, 1974; Caplan, Hildebrandt & Makris, 1996). Consequently, an alternative view on the role of Broca's area in language processing has been proposed, according to which Broca's area supports syntactic processing in both production and comprehension, while Wernicke's area supports lexical semantic processing (cf. Stowe, Haverkort & Zwarts, 2005).

Recently, the key role of the left inferior frontal gyrus (Broca's area) in syntactic processing has been questioned on the grounds that studies typically involve task and stimulus demands may activate brain regions that overlap with those involved in linguistic computations, making it difficult to differentiate between linguistic and non-linguistic processes (Tyler *et al.* 2011). As reviewed by Stowe, Haverkort & Zwarts (2005), recent neuroimaging evidence show that the left inferior frontal gyrus plays some role in comprehending sentences when processing is more difficult, but combined with the simple sentence results, they suggest that the left inferior frontal gyrus is not exclusively dedicated for syntactic processing. More recently, in a functional neuroimaging study of the linguistic performance in patients with left hemisphere damage and healthy participants, Tyler *et al.* (2011) have found that the left inferior frontal gyrus may not itself be specialized for syntactic processing, but plays an essential role in the neural network that carries out syntactic computations. This net involves a variety of brain areas co-activated with the left inferior frontal gyrus, including the right inferior frontal gyrus, bilateral superior temporal gyrus, left middle temporal gyrus and a more posterior temporo-parietal cluster including left inferior parietal lobule, left angular gyrus and left supramarginal gyrus. This suggests that the left inferior frontal gyrus plays an essential role within the neural language network, and that differential modulation within this network underpins different types of linguistic computations (Tyler, *et.al.* 2011).

It is evident that the view that Broca's area is a language-specific area can no longer be held in the light of evidence from recent imaging studies and lesion studies. From this view, Hagoort (2006: 246) argued strongly that "it would be a serious mistake to assume that Broca's area is a language-specific area." Instead, besides the classical Broca and Wernicke's areas, several additional distributed cortical and subcortical neuronal structures of both hemispheres clearly make a significant contribution to language function. Imaging and electrophysiological studies have identified an enlarged frontal region engaged in speech and language and Hagoort (2006:251) has called this enlarged area "Broca's complex," which refers to a series of related but distinct areas in the left prefrontal cortex, at least encompassing BAs 47, 45, and 44 and ventral BA 6. This set of areas subserves more than one function in the language domain and almost certainly other nonlinguistic functions as well. In the context of language processing, activation of this region is seen while experimental subjects engage in semantic (BA 47 and 45), syntactic (BA 45, 44, 46) and phonological processing (BA 44, 6). Broca's complex is thus involved in at least three different domains of language processing (semantic, syntactic, phonological), with substantial overlap (see figure 4). Thus, localizing Broca's region in the context of a functional imaging study analyzing linguistic material, or a lesion study of Broca's aphasia may refer to completely different areas with different cytoarchitecture, connectivity and, ultimately, function (Amunts 2008).

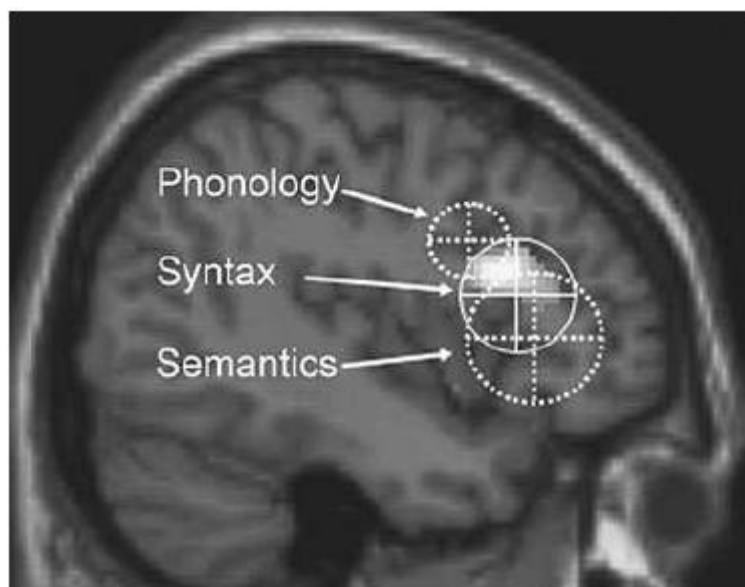


Figure 4: The gradient in left inferior frontal cortex for activations and their distribution, related to semantic, syntactic, and phonological processing. Adapted from Hagoort (2006).

Given the multiplicity of functions associated with Broca's area, a crucial question that arises is: Due to what extent one can claim a functional specificity to Broca's area? According to the connectionist model (e.g., Pulvermüller 2003), neurons develop billions of connections in a massively parallel network, in which no action or perception could be considered to have a single or simple "impulse." The brain activates many interconnected cortical nodes that are likely to participate in the function of more than one network. In this conception, Broca's area receives its specificity as part of a specialized network. It has been noted that particular neuroanatomical regions, including Broca's area, change their functions consequent upon the simultaneous activation of other regions that are effectively connected to a given region (cf. Fink *et.al.* 2006). Hence, context-dependent interactions within networks of areas determine the functions of the constituent areas. This notion of a distributed architecture of brain function suggests that a particular area may be part of different networks and hence its involvement in different functions depends on the input it receives in a given task context.

V. CONCLUDING REMARKS

One of the major hopes in investigating the neural correlates of language has always centered on the possibility of identifying the location of language in the brain. In fact, the results of deficit-lesion studies and neuroimaging studies have revealed much about the brain-language relationship though the issue of the neural organization of language remains a largely unexplained issue in view of the brain's complexity. Functional imaging findings reveal an array of brain areas involved in language processing, many of which are in conflict with long held assumptions about brain-language relationships. Not only the tradition of linking language-related functions with particular brain regions has been questioned, but a completely new perspective is also being offered. There is no single 'language area,' and it is likely that there is no language-specific area in the brain devoted to a specific function. A crucially important finding from such research is that the brain activates complex neural networks dispersed across both the left and the right hemispheres, even for simpler acts of cognition (Hellige, 2010). Therefore, any proposal of hemispheric specialization, such as saying that language depends on a relatively small area of the cortex or that a certain brain region can be exclusively dedicated to a certain function is unconvincing.

The same kind of consideration holds with regard to the postulation of a "language organ or module" (cf. Anderson and Lightfoot, 2002). Within current linguistics, the view of the brain as a "tabula rasa" for language has led some researchers to speculate that the brain consists of highly specialized language areas and/or circuits. The idea is also central to generative linguistics, i.e., the view that the language faculty is a module of the mind separate from other cognitive functions (Chomsky 1987). Such claims, however, are problematic as they opened the way to unnecessary entailments and to considerable misuse of the ideas that gave linguistics a bad name. Marshall termed this view of linguistics "the new organology" (Marshall, 1980:23). One reason for this is that so far, despite intensive research, no one has been able to find this organ or module. It is perhaps plausible to argue, as Jenkins (2000) did, that the proposition that there is a mental organ for language does not entail the proposition that the neural basis for such a mental organ is exclusively identified with any particular localized area. Rather, it "must be understood to include neural language circuitry with a possibly quite complex topological distribution" (Jenkins 2000:65).

Generally speaking, the findings uncovered by recent functional imaging research, reviewed in the present paper, suggest that language, as a special cognitive faculty, requires the interaction of numbers of highly integrated systems of the brain. This interaction involves both hemispheres as well as cortical and subcortical structures (Metter, 1995). Moreover, findings in the cognitive electrophysiology of language processing has made it clear that none of the ERP effects discovered to date seems to be unique to language processing. Neuroimaging data clearly suggest that key neural networks dedicated to language functions partially subserve nonlinguistic functions, such as executive system function, working memory, or attention control, which contribute reciprocally to aspects of language performance (Cahana-Amitay & Albert, 2014). These data, therefore, do not provide any evidence for the hard-wiring of anything as specific as language. Rather, it suggests a conception of language not a single process but a massively interconnected one; a neural network of cortical and subcortical regions, which participate in the performance of other cognitive processes in addition to language. Consequently, it is reasonable to argue, as Aydelott, Kutas, Federmeier (2005) did, that language specialty lies in being a cognitive faculty that requires such efficient and intricate integration of so many domain-general abilities, functions, and information sources.

The conclusion, thus, is that language does not have a dedicated set of cognitive/neural structures to draw upon. Rather it is a cognitive faculty that is intimately embedded in the general cognitive network. From this point of view, the proposal that there is an autonomous mental organ for language does not entail the proposition that the neural correlates for such a mental organ refer to discrete neural structures, but rather as a collection of interconnected neuronal pathways whose activation is related to language. This renewed view of the biological bases of language has challenged the classical assumptions about modularity, domain specificity, and the characterization of language disorders in terms of damage to language-specific processing modules. Researchers nowadays know that such a rigid locationist theory is implausible for two reasons: one function involves more than one cortical area and more than one portion of the brain. Conversely, the cortical areas and the portions of the brain that are involved can play a role in other functions as well. However, evidence from physiological studies and deficit analysis indicates that the conception of modularity of language functions is useful provided that these functions participate in more diffusely distributed processes (cf. Kertesz & Wallesch, 1993). Thus, Carston (1997: 20; as quoted in Hudson, 2007:6) notes that "we have to rethink the concept of module and allow for a kind of continuum, from peripheral perceptual systems, which are rigidly encapsulated (not diverted from registering what is out there), through a hierarchy of conceptual modules, with the property of encapsulation diminishing progressively at each level as the interconnections among domain-specific processors increase." This suggests that a model of brain functioning needs to include both a localization and a distributed processing perspective.

Despite a great deal of progress has been made in understanding the neural mechanisms that underlie language, the problems of relating neural structures and dynamics to specific cognitive functions, including language processes, are many. Indeed, functional imaging techniques have been useful in identifying the areas that become active during linguistic stimuli as well as in identifying several neural interfaces among language, cognitive, motor, and sensory processes (cf. Cahana-Amitay & Albert, 2014). However, to the best of my knowledge, even the use of such modern research techniques has not definitively answered how and exactly and precisely which cortical-subcortical structures are involved in language functions. A significant challenge has been the manner in which the different elements of the neural networks work and coordinate their activity to execute the complex functions they support (Hellige, 2010). To identify the network of connections throughout the brain that deal with this uniquely human ability and its brain substrates, including the functional contributions of nonlinguistic skills, is a major challenge for the neurosciences in the twenty-first century (Friston, Harrison & Penny, 2003).

Finally, this overview of the current state of knowledge on topics related to brain-language relations clearly indicates that the field of brain-language search is still at its infancy with numerous exciting avenues for future research. There has been extraordinary progress made in recent years in genetics, embryology, and developmental neuroscience. New and important discoveries may come from the use of electrophysiological techniques such as transcranial magnetic stimulation (TMS) or evoked potentials (for a review of these techniques, see Calvin and Ojemann, 1994.) Finally, in vivo brain investigation makes use of a combination of neuroradiology and computer science in order to produce investigative techniques such fMRI or PET. Research using these techniques may open new perspectives on how human brain supports language functions. One important aspect of this enterprise is that it is truly multi-disciplinary, involving cooperation between linguistics, psychology, genetics, neuroanatomy and other related disciplines.

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