Comprehension of Wh-Dependencies in Broca's Aphasia

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To the memory of my father,
Radoje Kljajević

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ACKNOWLEDGMENTS

This book is a re-written version of the 2005 doctoral dissertation I produced at the Institute of Cognitive Science, Carleton University, Ottawa. This new version has been updated to include a more developed morphological account of the data that was only sketched in the original version as well as a number of research findings that have been published since completion of the original. The result, I hope, is a clearer picture of the comprehension of *wh*-dependencies in Croatian aphasic speakers.

The research reported in this book was conducted under the guidance of Marie-Odile Junker and Kumiko Murasugi, whom I would like to thank for their helpful advice and encouragement. I would also like to thank Jack Kelly, Monique Sénéchal and Eta Schneiderman for their comments on the reported research. I am grateful to Vida Demarin, Višnja Akrap-Kotevski, Zvjezdana Trifunović, and Marija Paškvalin from Zagreb for their assistance in finding aphasic patients for the study. Thanks are due to Don Ross for his editorial help. Finally, I would like to thank my family and friends for their encouragement during the preparation of this book.

LIST OF ABBREVIATIONS

Acc	Accusative
BA	Brodmann area
BDAE	Boston Diagnostic Aphasia Examination
CT	computed tomography
DAH	Direct Association Theory
DQ	direct questions
ECA	external carotid artery
ERP	Event Related Brain Potentials
EQ	embedded questions
EQ1PP	embedded questions with 1 prepositional phrase (PP)
EQ2PPs	embedded questions with 2 prepositional phrases (PPs)
f.	feminine
fMRI	functional Magnetic Resonance Imaging
GB	Government and Binding Theory
GG	Generative Grammar
ICA	internal carotid artery
lpt.	l-participle
LAN	left anterior negativity
LD	long-distance questions
LD *za*	long-distance questions with the preposition *za*
LTM	long-term memory
m.	masculine
MCA	middle cerebral artery
n.	neuter
Nom	Nominative
NP	noun phrase
OAA	overarching agrammatism
p.	plural
Pass.	passive
past	past tense
PCA	posterior cerebral artery
PET	positron emission tomography
PQ	passivized questions
pres.	present tense
RC	relative clauses

RCPM	Raven's Colored Progressive Matrices
RTDH	Revised Trace Deletion Hypothesis
s.	singular
SPLT	Syntactic Prediction Locality Theory
SOV	Subject-Object-Verb word order
SVO	Subject-Verb-Object word order
SWM	syntactic working memory
TBA	Trace Based Account
TDH	Trace Deletion Hypothesis
VP	verb phrase
WM	working memory

CHAPTER ONE

INTRODUCTION

1. Language Comprehension Architecture

Language is embedded in cognition and as such it is neither a unified nor isolated phenomenon. Many neurobiological and computational processes are involved in language processing. For example, speech perception and reading require perceptual transformations in the auditory and visual cortices (Hickok & Poeppel, 2004). Speaking requires motor control processes supported by the motor cortical areas, basal ganglia and cerebellum (Kutas, Federmeier, Coulson, King & Münte, 2000). Auditory language comprehension, which is the focus of this book, is carried out by several language subsystems, such as the phonological, semantic and syntactic subsystems, and is supported by memory and attentional processes.

The phonological subsystem of auditory comprehension carries out phonetic and phonological processes. Neuroimaging evidence suggests that this subsystem involves certain temporal areas bilaterally as well as the left dorsal portion of the Brodmann area (BA) 44 (Price, 2010). The semantic subsystem in auditory comprehension activates several areas, depending on the nature of the semantic task: while passive listening activates temporal region BA 22/42 bilaterally, other semantic tasks activate anterior and posterior parts of the left middle temporal gyrus (BA 21), bilateral anterior temporal poles (BA 38), left angular gyrus (BA 39), as well as left pars orbitalis (BA 47), pars triangularis (BA 45), middle frontal gyrus (BA 46), and pars opercularis (BA 44) (Friederici, 1998; Price, 2010). The syntactic subsystem involved in sentence comprehension activates Broca's area (BAs 44, 45), BA 39, the supramarginal gyrus (BA 40), and the superior temporal gyrus (BA 22) of the dominant hemisphere (Stromswold, Caplan, Alpert & Rauch, 1996; Grodzinsky, 2000b; Caplan, Vijayan, Kuperberg, West, Waters, Greve & Dale, 2001; Fiebach, Schlesewsky, Lohmann, von Cramon & Friederici, 2004). Computationally more demanding tasks affect the brain responses, resulting in variability in activation (Just, Carpenter, Keller, Eddy & Thulborn, 1996).

The auditory language comprehension also depends on the functional connectivity between brain areas and so the white matter pathways, such as the inferior occipito-frontal fasciculus, the arcuate fasciculus, and the middle and inferior longitudinal fasciculi are highly relevant for comprehension processes (Turken & Dronkers, 2011). Furthermore, there are indications that some subcortical structures related to rule-based elements of processing, such as the basal ganglia, are also involved in syntactic comprehension (Caplan, 2002).

As a higher cognitive function, language is supported by other cognitive systems, such as memory and attention. This further means that the parietal lobe, which is implicated in attentional processes, and the hippocampal, medial temporal, and frontal lobe structures, as implicated in memory processes, also support language processing (Kutas et al., 2000). Thus, many areas of the brain are involved in language processing and the relationship between the processing components and cortical regions is rather complex. In computational terms, it means that the processing of language requires resources from more than one cognitive domain.

Until recently, the role of memory and attention in comprehension and other language processes had been overlooked. Two steps were necessary to overcome this problem: first, it was essential to recognize that each of these cognitive domains makes their respective resources available to information processing, and second, it was necessary to define the nature of systems such as working memory (WM) that link cognitive information from different domains (Van der Zee & Nikanne, 2000). Indeed, growing interest in the role of WM in language comprehension has already created a dynamic field which incorporates theoretical knowledge, methodology and empirical findings from several disciplines (Caplan et al., 2001; Embick, Marantz, Miyashita, O'Neil & Sakai, 2000; Felser, Clahsen, Münte, 2003; Just et al, 1996; Kang, Constable, Gore & Avrutin, 1999; Keller, Carpenter & Just, 2001; Kotz & Friederici, 2003; Münte & Heinze, 1994; Stowe, Withaar, Wijers, Broere & Paans, 2002; Swaab, Brown & Hagoort, 1997; Vos, Gunter, Schriefers & Friederici, 2001; among others). While there is general agreement that without WM it would not be possible to temporarily store intermediate representations on which subsequent processes operate (which is crucial in any kind of syntax), research on the impact of WM on the comprehension of syntax of language (syntactic comprehension) has resulted in conflicting conclusions (Just & Carpenter, 1992; Martin & Romani, 1994; Miyake, Carpenter & Just, 1994, 1995; Caplan & Waters, 1999, 2002; Crosson et al., 1999; Vos et al., 2001). This is not a trivial matter, since it leaves open issues of theoretical framework, interpretation of empirical findings and choice of appropriate research methods. This is particularly evident in research on Broca's aphasia, a language disorder caused by focal brain damage, which is also characterized by limited processing resources and slowed access to linguistic information (Kolk & Heeschen, 1990; Prather, Shapiro, Zurif & Swinney, 1991; Kolk, 1995; Zurif et al., 1993; Frazier & McNamara, 1995; Swinney, Zurif, Prather & Love, 1996; Swaab et al., 1997).

2. Sentence Comprehension in Broca's Aphasia

Due to the effortful, halting speech Broca's aphasics produce, and their omission of function words (also known as closed-class words) such as auxiliaries and copulas, Broca's aphasia was originally qualified as a disorder limited to speech production. However, Caramazza and Zurif (1976) found that English speaking Broca's aphasics also had difficulty with syntactic comprehension, in particular when sentence meaning was not facilitated by semantic or pragmatic cues indicating thematic roles and depended on syntactic information, as in semantically reversible object relative center-embedded sentences in (1).

(1) The boy that the girl is kissing is happy.

Subsequent work has confirmed the finding, and in further examining whether the syntactic comprehension deficit in Broca's aphasic patients is manifested in other syntactic structures as well, researchers came to the conclusion that there exists a comprehension pattern of sparing and deficit in this population. The pattern can be described in the following way: Broca's aphasics show deficient syntactic comprehension in structures that include extraction from the object position, as in (1), while their comprehension of structures with extraction from the subject position, such as in (2), is relatively spared (Caplan & Futter, 1986; Grodzinsky, 1990; Hickok, Zurif & Canseco-Gonzalez, 1993).

(2) The boy who is kissing the girl is happy.

In contrast to English, which marks grammatical relations by word order and use of prepositions, languages with rich inflection and relatively free word order, such as Croatian, in general use case inflection to mark these relations. Interpretation of the Croatian counterpart to (1) and (2) does not depend on word order. This means that the processing of syntax in morphologically rich languages is facilitated by inflectional cues. These, however, are by definition impaired in Broca's aphasia (Caramazza & Zurif, 1976; Grodzinsky, 1984; Badecker & Caramazza, 1985; Goodglass, 1993; Caplan, 1995; Zurif, 1995). A failure to interpret a sentence may occur even when a patient's ability to process grammatical morphemes is spared. For example, Caramazza and Miceli (1991) report a dissociation between spared processing of morphological information in a sentence and impairment in thematic roles assignment in active and passive reversible sentences. The dissociation indicates a separate thematic roles processor that functions independently from other processors (Caramazza & Miceli, 1991).

Cross-linguistic research on aphasia has provided abundant evidence that manifestations of the deficit differ across languages, which is not surprising given that languages differ structurally (Grodzinsky, 1984). For example, dropping articles in speech production is typical of English-speaking Broca's aphasics. Yet this is not an option in Croatian, because this language does not have articles.

Smith and Mimica (1984) tested comprehension of semantically reversible passive sentences in 10 Serbo-Croatian[1] Broca's aphasics using the act-out testing paradigm[2]. They found that Broca's aphasics showed "some sensitivity" to case inflection, and that, when sentence comprehension was in addition facilitated by other cues (semantic cues and word position in a sentence), their aphasics' comprehension was close to that of neurologically intact control subjects. Although they used a different testing paradigm (grammaticality judgements), Lukatela, Crain and Shankweiler (1988) also found that 6 Serbo-Croatian speaking Broca's aphasics "retained sensitivity to the closed-class morphology" when sentence comprehension exclusively depended on case inflection (p. 7). Thus, Serbo-Croatian-speaking aphasics showed that they could exploit grammatical information conveyed by case inflection to different degrees, depending on the type of task. These findings challenge the claim that use of inflectional morphology is reduced in Broca's aphasics, giving rise to the claim that the deficit manifests differently in structurally different languages (Paradis, 2001).

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[1] In this book I use the term *Serbo-Croatian* only when reporting or commenting on works that were published before the Croatian language was officially established (1991), or when referring to the works of those researchers who still use the term *Serbo-Croatian* for both Serbian and Croatian. Otherwise, I use the term *Croatian*.

[2] See section 6.2.1 on paradigms used in testing aphasic populations.

Lukatela (1989) tested comprehension of semantically reversible subject and object relative clauses formed by *koji* “which” in 7 Broca’s and 5 Wernicke’s Serbo-Croatian speaking aphasics. She found that Broca’s performed better than Wernicke’s aphasics on all types of relative clauses, and that, as with English aphasics (Caramazza & Zurif, 1976), object relative clauses were most difficult for Serbo-Croatian aphasics. However, unlike English Broca’s aphasics, who comprehended object relatives at chance level, 4 out of 7 Serbo-Croatian speaking Broca’s aphasics tested by Lukatela (1989) and further analysed by her and her colleagues, performed above chance on these structures (Lukatela, Shankweiler & Crain, 1995).

Thus, given the structural differences between English and Croatian, and the findings indicating that Serbo-Croatian Broca’s aphasics (a) can employ inflectional cues to some extent, and (b) comprehend object relative clauses above the chance level, the question that emerges is: How do they comprehend structures where the grammatical function of the object is unambiguously signalled by case inflection on a word in sentence initial position? Such structures are direct object *who* (3) and *which NP* questions (4).

(3) Koga je lane liznulo?
“Who did the fawn lick?”
(4) Koje ždrijebe je žirafa ritnula?
“Which foal did the giraffe kick?”

In this book I explore how Croatian-speaking Broca’s and patients with mixed aphasia comprehend *who* and *which NP* direct questions and other *wh*-dependencies, assuming that the processing of complex syntax requires a comprehension system that engages a network of brain areas implicated in functioning of different subsystems.

There are three main reasons for undertaking this research. First, previous studies on the comprehension of *wh*-dependencies in English-speaking agrammatic Broca’s aphasics have reported contradictory findings. Hickok and Avrutin (1996) argue that Broca’s aphasics display the following pattern in the comprehension of *wh*-questions:
(a) good comprehension of both subject and object direct *who* questions;
(b) good comprehension of subject, but poor comprehension of object direct *which NP* questions.

However, attempts to replicate the pattern were only partially successful: Tait, Thompson and Ballard, (1995) found that only 2 in 4, and Thomspon, Tait, Ballard and Fix (1999) showed that only 1 out of 4

Broca's aphasics followed the pattern. Salis and Edwards (2008) tested 5 English-speaking Broca's aphasics and found that the pattern of comprehension deficit in their patients did not match the pattern reported by Hickok and Avrutin. In a study with 9 German-speaking Broca's aphasics, Neuhaus and Penke (2008) found that the comprehension pattern of 3 patients did match the *who/which* pattern described above. Taken together, these findings indicate that additional crosslinguistic evidence on processing of *wh*-structures in aphasia is much needed.

Second, among the proposals that have been put forth to explain the pattern, two suggest structural explanations in terms of Universal Grammar (Hickok & Avrutin, 1996; Thompson et al.[3], 1999), implying that the pattern should exist cross-linguistically. By presenting data from a language structurally different from English, such as Croatian, this book intends to explore the cross-linguistic potential of the pattern and applicability of the proposed structural explanations.

Third, the book intends to further our understanding of computational processes involved in comprehension of complex syntax.

2.1 Computational or Conceptual Deficit?

There are two main approaches in the study of comprehension deficits in Broca's aphasia: the conceptual or structural, and the computational or processing accounts (Caplan, 1988; Frazier & Friederici, 1991; Lukatela et al., 1995). The processing theories explain the nature of the deficit in Broca's aphasics' comprehension in terms of an impaired access to knowledge (Linebarger, Schwartz & Saffran, 1983; Smith & Mimica, 1984; Caplan & Hildebrandt, 1988; Haarmann & Kolk, 1991; Lukatela et al., 1995; Tait et al, 1995; Thompson et al., 1999; Avrutin, 2000), while the structural theories explain the deficit as a loss of knowledge, either a complete (Caramazza & Zurif, 1976; Berndt & Caramazza, 1980) or partial loss of syntax (Grodzinsky, 1986; 1990; Hickok et al, 1993; Mauner, Fromkin & Cornell, 1993; Hickok & Avrutin, 1996).

The structural approach is based on the idea that damage to a component of Broca's area - such as the pars opercularis (BA 44) - wipes out part of syntax. The original localization theory, which associates specific brain areas with particular cognitive functions, assumed that Broca's area was a language area involved in speech production (see Caplan, 1995, and Goodglass, 1993, for an overview). The theory has been

[3] Thompson et al. (1999) actually present a semantic approach, but they also suggest a syntactic analysis in terms of Universal Grammar.

challenged on different grounds over time (Uttal, 2001), only to reappear recently, reinstated by researchers who argue that Broca's area is in fact the locus of a specific syntactic computation (Grodzinsky, 2000b). Since this area is typically damaged in Broca's aphasic patients, careful analyses of syntactic processing in this population were conducted in an attempt to correlate damage to component(s) of Broca's area with types of syntactic deficits.

There are two problems with this approach. First, growing evidence shows that Broca's area supports a variety of tasks not necessarily related to syntax or language in general[4]. Second, damage to Broca's area alone leads to transient disturbances, while Broca's aphasia is associated with larger, deeper lesions encompassing Broca's area (Dronkers, Pinker & Damasio, 2000). Thus, it is necessary to discern which components of syntactic processing are supported by Broca's area, and define other brain areas that also support syntactic processing.

Embick at al. (2000), for example, claim that the exclusive role of Broca's area is to regulate comprehension of specific intrasentential dependencies. Evidence from lesion studies suggests that these dependencies are related to syntactic movement, a specific process of forming complex syntactic structures, such as those in (3) and (4) (Grodzinsky, 2000b). Based on the functional Magnetic Resonance Imaging (fMRI) experiments conducted with healthy native Hebrew-speaking population, Ben-Shachar, Palti and Grodzinsky (2004) found a finer distinction in neurological areas involved in syntactic movement: both the left inferior frontal gyrus and left anterior insula are sensitive to movement operations. Friederici, Rüschemeyer, Hahne and Fiebach (2003) conducted fMRI experiments with a neurologically intact, German-speaking population and found that the anterior portion of the inferior frontal gyrus (BA 44 on the border to BA 45) and BA 47 are implicated in processing of long-distance dependencies, while "the posterior-inferior portion of BA 44, i.e., the inferior tip of the pars opercularis and deep frontal operculum on the border to ventral premotor cortex, is involved in on-line syntactic structure building processes" (p. 171). Nagai, Inui and Iwata (2010) present further evidence for the functional segregation of Broca's area. In a study with four Japanese Broca's aphasics, they found that the pars opercularis is involved in operational and the pars triangularis in semantic aspects of syntactic processing.

[4] Leaving aside the debate on the role of Broca's area in cognition, perception, and action (Kljajevic, 2011b), here I focus on the role of this area in syntactic processing of language.

Contrary to the representatives of the structural approach, proponents of the processing approach claim that Broca's area is not the locus of syntax *per se*. For example, Zurif (1995) claims that it houses processing resources implicated in "lexical (re)activation and its syntactic ramifications" (p. 394). In an Event Related Brain Potential (ERP) study that investigated auditory sentence comprehension in Broca's and Wernicke's aphasics, Swaab et al. (1997) found that aphasics' comprehension problems were due to an impairment of the process of integration of lexical information into the overall message representation: aphasics were slower than normal participants, and the delay in integration affected their comprehension.

Based on ERP and fMRI experiments conducted with neurologically intact native speakers of German, Fiebach, Schlesewsky and Friederici (2001, 2002) propose that Broca's area actually houses syntactic WM, assuming that a particular type of processing cost is implicated in comprehension of syntactic structures. While the findings on the involvement of Broca's area in an aspect of WM do not coincide with the evidence indicating the involvement of the mid-dorsolateral frontal cortex (BAs 46 and 9) in the verbal domain of WM (e.g., Petrides, Alivisatos, Meyer & Evans, 1993), Fiebach et al.'s (2001, 2002) view has been supported by further evidence (e.g., Felser, Clahsen & Münte, 2003; Fiebach et al., 2004).

Kennedy and Small (2002) conducted a cross-domain behavioral study in order to determine whether the WM resources required for comprehension of sentences that pose high WM demands are domain- (i.e., language-)specific. They used tasks matched for WM processing demands in language, mathematic and visuo-spatial WM contexts. Details aside, the mathematic and visuo-spatial tasks were intended to mimic processing demands of subject and object relative clauses (e.g., the brackets in a math task function as embedding within a sentence). They found that the "similarity of the sequence of demands" to the sentence processing task, and not the similarity of the cognitive domain, triggered similar WM demands and thus similar patterns of activity across the domains. Patel (2003, 2008) and Fedorenko, Patel, Cassanto, Winawer and Gibson (2009) discuss multimodal evidence for the shared syntactic integration resources hypothesis (SSIRH), according to which language and music share cognitive and neural resources, despite representing two different domains and employing different types of representations. Thus, perhaps a more plausible approach to the role of Broca's area in syntactic processing is one that applies the concept of syntax not exclusively to language, but rather assumes, like Townsend & Bever (2001), that syntax is a formal property of any activity based on computation[5].

Several fMRI studies have shown that increased sentential complexity correlates with an increase in activation of Broca's area (Just et al., 1996; Embick et al., 2000; Keller et al., 2001). If a general increase in complexity (and thus computation), rather than a specific syntactic process, is a reason for increase in activation in Broca's area, then this is further evidence that something other than syntax *per se* may be compromised in Broca's aphasic patients.

Additional evidence for this claim comes from early experiments on grammaticality judgements conducted with English speaking Broca's aphasic patients (Linebarger et al., 1983; see also Lukatela, (1989) for evidence from Serbian). The experiments have shown that grammatical knowledge in these patients was preserved, indicating that if the deficit typical for the syndrome is not in loss of knowledge of grammar, then it is probably processing that is disrupted in these patients.

This book investigates both structural and processing approaches in explaining the comprehension deficit of *wh*-dependencies in Broca's aphasia. It also examines recent research on processing of *wh*-dependencies in a population without neurological damage. By applying some of the ideas developed in research on processing of complex syntax in neurologically intact populations to comprehension deficits in aphasic patients, the book brings together research on damaged and neurologically intact brains.

The book consists of 9 chapters. Chapter 1 is a brief introduction to the topic of the study. Chapter 2 introduces theoretical concepts on aphasia that the study deals with: aphasia caused by a stroke, the syndrome approach to aphasia, with a special emphasize on Broca's aphasia, and the concept of agrammatism. Chapter 3 is a description of *wh*-dependencies in English and Croatian. Chapter 4 presents a theory within which most of the research on comprehension of syntax in Broca's aphasia has been conducted by now: the Government and Binding theory (Chomsky, 1981), and a theoretical account of the differences between *who* and *which NP* types of questions. This chapter also presents the general pattern and the *who/which NP* pattern of syntactic comprehension deficit in Broca's aphasia, as well as proposed structural explanations. The main topic of Chapter 5 is the processing cost of comprehension of *wh*-dependencies. Chapter 6 summarizes the research questions, introduces the hypothesis of

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[5] "Syntax is not a unique formal property of linguistic computation, but it is part of vision, motor behavior, and every other activity with a computational basis" (Townsend & Bever, 2001, p. 1).

the present study, describes the evaluative and experimental measures and the procedures used, and briefly introduces the participants. Chapter 7 consists of eight case studies. Each case study contains information on lesion site and type of stroke in a particular patient, description of his/her spontaneous speech as well as the results of his/her performance on evaluative and experimental measures. Abstracting away from the comprehension problems of individual patients reported in Chapter 7, Chapter 8 analyzes them in terms of syntax and processing, directing the general discussion towards the implications of the findings of this study and research on language disorders for our understanding of language and cognition. Chapter 9 concludes the book by placing the gained insights in a wider theoretical context.

CHAPTER TWO

BROCA'S APHASIA

2.1 Aphasia Caused by Stroke

Aphasia is a language disorder caused by brain damage. The defining factors of aphasia are location of lesion and etiology (Benson & Ardila, 1996). Regardless of whether aphasia is caused by a vascular, traumatic, infectious, or surgical cause, its symptoms always reflect language impairment (Darley, 1982).

Most research on aphasia so far has focused on post-stroke aphasia. Stroke is among the leading causes of disability worldwide. It is also the most common cause of aphasia (Tonkonogy, 1986), which, according to some authors, leaves 20–25% of patients initially aphasic (Reinvang, 1985), while others claim that 40% of all strokes result in this disorder (Gazanniga, Ivry & Mangun, 1998).

Stroke or cerebrovascular incident is a sudden loss of circulation to an area of the brain, which causes loss or impairment of function performed by that brain area (Caplan, 2000). Two major types of stroke are ischemia and hemorrhage. In general, 80% of all strokes are categorized as acute ischemic stroke. Ischemia occurs when the blood flow to the brain tissue is either disrupted due to an occlusion of one or more blood vessels (thrombosis and embolic stroke), or is diminished due to low systemic perfusion pressure (decreased systemic perfusion). Hemorrhage is blood leakage into the brain (intracerebral hemorrhage) or into the spaces around the brain (subarachnoid hemorrhage). Stroke lesions are typically large and affect more than a single brain area, causing impairment in more than one language modality in many cases.

2.2 Classification of Aphasias

A failure of specific components of the cerebrovascular system can affect functioning of different parts of the brain. Language functioning is affected differently by damage to different parts of the brain due to stroke.

Several types of aphasia have been defined based on this neurological approach: Broca's, Wernicke's, transcortical motor aphasia, transcortical sensory aphasia, conduction, global, and anomic aphasia. There are over 20 different classifications of aphasias (Ardila, 2010), but this anatomically based syndrome typology is most dominant (Goodglass, 1993; Caplan, 1995; Basso, 2003). It classifies aphasias according to whether they result from disturbances of cortical centers (i.e., Broca's aphasia is caused by damage to Broca's area, Wernicke's aphasia results from damage to Wernicke's area) or from disruptions of connections between the centers (e.g., conduction aphasia is caused by disruption of the arcuate fasciculus) (Caplan, 1995).

This type of aphasia classification has been criticized on several grounds. For instance:

a) Goodglass (1993) and Caplan (1995) have pointed out that syndromes are too rigid to capture fuzzy areas between different types of aphasia. The clear-cut distinctions among language deficits associated with different syndromes do not reflect clinical reality (Caplan, 1995; Goodglass, 1993). For instance, a patient who is capable of producing only one-word utterances and has impaired articulation and relatively impaired comprehension, and a patient who has normal articulation but agrammatic speech output and good comprehension, are both qualified as Broca's aphasics (Goodglass, 1993).
b) The syndromes are too wide and too narrow at the same time. For example, overlapping features characterize separate syndromes: phonemic (i.e., literal) paraphasias, i.e., faulty selection of sounds, are present in Wernicke's, conduction, and global aphasias, while anomia characterizes all aphasias. However, a patient exhibiting only phonemic paraphasias and anomia cannot be classified according to this typology and as a result many cases with mixed symptoms are unclassifiable (Caplan, 1995).
c) The syndrome approach relies heavily on anatomical criteria, although they are inconsistent. For example, as Goodglass (1993) pointed out, it is not clear how to classify a disorder with characteristics of Wernicke's speech in a patient without a lesion in the temporal lobe. Similarly, different types of aphasia can follow damage to the same brain area. As an example, researchers who studied aphasia secondary to lesion of the basal ganglia, more specifically striatocapsular infarction (infarction of the head of the caudate nucleus, the putamen, and the anterior limb of the internal capsule), found that this lesion site is associated with Broca's, transcortical motor, Wernicke's,

conduction, global and anomic aphasia, or with no aphasia at all (Nadeu & Crosson, 1997).

d) The syndrome approach is incoherent with regard to the criteria it applies in classification. It mixes criteria from different domains: a certain type of aphasia is classified as such based on the type of channels that are involved (e.g., sensory vs. motor channels), the type of produced linguistic errors (e.g., agrammatism, paraphasias anomia) and impressions of fluency (fluent vs. non-fluent) (Goodglass, 1993).
e) The syndrome approach describes types of aphasia as "fixed patterns of linguistic behaviour", despite possible differences in language performance due to severity of aphasia and individual differences (Goodglass, 1993).
f) The classical syndrome approach to aphasia cannot capture the intra- and inter-individual differences (Goodglass, 1993; Murray, 1999). As an example, Bastiaanse (1995) reports on a patient who shifted between short, well-formed sentences and agrammatic speech during a single interview.
g) The syndrome approach also assumes that language is a set of activities such as naming, writing, reading, speaking (Grodzinsky, 2000b). From the linguistic point of view, this means that the syndrome approach fails to recognize language as a system of knowledge organized into subsystems (modules) that can be selectively disrupted depending on the brain damage. In the linguistic literature, this knowledge has been referred to as *linguistic competence*, as opposed to *linguistic performance,* i.e., actual use of language (Chomsky, 1981). By failing to recognize this distinction, the classical syndrome approach falls behind the recent insights on language.

Some researchers have pointed out that the cause of the problem with the classification of aphasias is the concept of syndrome itself (Berndt & Caramazza, 1980), while others have emphasized the lack of consensus on how to classify the various manifestations of aphasia (Caplan, 1995; Goodglass, 1993). Another view emphasizes that after a brain injury, behaviour results from the functioning of the entire brain, and symptoms are therefore "not manifestations of the injured brain region, rather they are expression of plastic changes in the rest of the brain" (Pascual-Leone, Amedi, Fregni & Marabet, 2005).

Few workable alternatives to the classical syndrome approach have been formulated. One possibility is a cognitive approach to language disorders, i.e., search for the underlying cause of a deficit, and its interpretation in terms of modularity (or differently interpreted functional organization of cognition). The modular approach is based on the idea that the functional architecture of cognition is organized in such a way that language processing is carried out by processing modules (components) that are presumably common to and arranged in the same way in all language users. As a focal brain injury, aphasia can disrupt functioning of a specific component of the normal functional architecture, sparing other components. Thus, the cognitive approach to aphasia has advantages over the syndromic approach in relating functioning of damaged and neurologically intact brains. However, this approach seems to leave open the question of how to best classify aphasic patients.

Another option is a clinical nonsyndromic approach, which briefly describes a particular case of aphasia as a cluster of symptoms, capturing at the same time all the details of a specific case (Goodglass, 1993). The advantage of this approach over the classic syndromic approach is that it allows occurrence of both prototypical and borderline cases without forcing the mixed cases into “pure” syndromes.

If genuine explanations explain phenomena in a principled way, then in the case of language such an explanation would link normal language processing with its furthest poles in both directions: language acquisition and language disorders. Assuming that aphasics’ language is essentially different from language produced by a neurologically intact brain, the syndrome approach has missed linking the three domains.

Until recently, most of the research on aphasia neglected the fact that other sources of information (e.g., visual) are present simultaneously with language information, and that other types of cognitive resources (e.g., memory, attention) are engaged in language processing. For example, although critical in syntactic processing, the role of WM in aphasic language processing has begun to be investigated only recently. Research on aphasia and attention is also sparse, although it is reasonable to assume with Murray (1999) that the within-subject variability is probably caused by attention deficits typically present in aphasic patients.

Instead of approaching aphasia as an isolated cognitive accident manifested as language disturbance of a type that depends on lesion site, and given the lack of typology that overcomes the drawbacks of the dominant approach discussed above, in this book I consider all the symptoms of a particular case available from the medical documentation, whether they fit into the classic definition of the syndrome or not, as well as all the available characteristics of that person’s speech and comprehension as revealed by the evaluative and experimental measures (see Chapter 7).

2.3 Broca’s Aphasia from a Neuroanatomical Perspective

One common traditional definition of Broca’s aphasia assumes a language disorder due to a lesion in Broca's area, which has been described as a *classical language area* implicated in speech production. However, this view has been challenged due to growing evidence indicating that Broca's area contributes not only to speech, but also to other aspects of language, supporting tasks unrelated to language as well, such as memory tasks, action observation, mental imagery of movement, musical syntax, processing of complex geometric patterns, and so on. These findings indicate that some traditional assumptions on Broca’s area do not hold[1]. Furthermore, Broca’s aphasia has been associated with lesions in other brain areas, and it has also been shown that lesion in the left inferior frontal gyrus (LIFG) alone does not cause the classical Broca’s aphasia. A revised notion of lesion causing the syndrome includes some combination of the LIFG with other brain areas. Depending on this combination, three distinct subtypes of Broca’s aphasia are now discernible (Alexander, Naeser & Palumbo, 1990).

2.3.1 From *Circonvolution du Langage* to Broca’s Area

In a recent metaanalysis of 542 articles containing the term Broca’s area/region, published between 1994 and 2004, Lindenberg, Fangerau and Seitz (2007) found that the term Broca’s area was not defined in 21% of these papers. Of those that defined the term, 97% of papers specified it anatomically (either cytoarchitectonically or macroscopically) and 3% determined it functionally. However, Broca’s area as an anatomical concept is heterogeneous: when determined cytoarchitectonically in terms of BAs, it is consistently defined as BAs 44 and 45 in only 27% of papers, while in the rest of papers the term refers to BA 44 in some papers and includes (some combination of) BAs 44, 45, 47, 46, and 6, in others. In addition, descriptive terms such as a *Broca’s area proper* or *restricted Broca’s area*, on one side, and an *extended Broca’s area*, *Broca’s region*, *Broca’s complex*, *Broca’s area as a large area*, on the other, are also in use. Furthermore, the area is often described in terms of gyral patterns and sulcal landmarks, even though the boundaries of the macroscopic landmarks do not always coincide with the microscopic boundaries (Amunts, Schleicher, Bürgel, Mohlberg, Uylings & Zilles, 1999).

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[1] Parts of Section 2.3 appeared in my paper *Broca’s Area: Four Misconceptions*, in: *Current Topics in Neurology, Psychiatry and Related Disciplines, 19(1)*, 20-30.

Functional and neuroanatomical heterogeneity of other language areas, such as Wernicke’s, have also been demonstrated (Wise, Scott, Blank, Mummery, Murphy & Warburton, 2001). For instance, damage to the fronto-temporal region of Wernicke’s area has been associated with lexical processing impairment, while damage to the parietal-temporal region of this area has been associated with a syntactic processing deficit (Caramazza & Zurif, 1976). This evidence further highlights the need to re-examine the neuroanatomical classification of aphasia.

Broca's area is a complex concept that has become associated with a loss of speech in two patients described by Pierre Paul Broca in the 1860s. Its status as a *classical language area* supporting speech production, or *the motor center for speech*, had remained intact for more than 100 years, only to become challenged in light of neuroimaging evidence. Neuroanatomically, the area was associated with the site of lesion that allegedly caused the loss of speech in Broca’s patients Leborgne and Lelong—the LIFG.

The development of the term from *circonvolution du langage* to *Broca’s area* began in the 1860s, when Broca reported that his two now famous patients, Leborgne and Lelong, who exhibited a profound speech loss, had damage to the inferior frontal gyrus of the left brain hemisphere. Broca hypothesized that this brain area was responsible for speech production and named the disorder *aphemia* (Greek a “without”, phemia “speech”), intending to convey the idea that the disorder had spared the language faculty, selectively affecting only the faculty of speech. At autopsy Broca found that for instance Leborgne’s lesion was much larger, affecting in addition to the posterior half of the inferior frontal gyrus, the middle frontal gyrus, insula, and the striate body (Broca, 1861/2001). Broca argued that Leborgne’s lesion had been progressive, originating probably at the IFG, spreading over the frontal gyri, and eventually reaching the insula and the striate body. As a consequence, in addition to speech loss, which had characterized the first ten years of his illness, Leborgne had experienced a general cognitive decline, and the right limbs’ paralysis during the last eleven years of his life.

The brains of Leborgne and Lelong, which have been preserved and kept in the Musee Dupuytren in Paris, France, were recently inspected by the techniques such as computerized tomography (CT) and magnetic resonance imaging (MRI). These techniques revealed that Leborgne’s lesion in the frontal lobe was in the middle third, not in the posterior third, of the inferior frontal gyrus (Dronkers, Plaisant, Iba-Zizen & Cabanis, 2007), affecting entire insula and the basal ganglia, while Lelong's lesion affected half of the pars opercularis in the posterior, inferior frontal gyrus (BA 44), while sparing the pars triangularis (BA 45). In addition, both patients had damage to the arcuate/superior longitudinal fasciculus. Thus, both brains had lesions that are inconsistent with the current concept of Broca's area, which is restricted to the posterior third of the LIFG. More importantly, they both had damage to the arcuate/superior longitudinal fasciculus, which seems to be a more likely cause of the profound, long-lasting speech production deficit in these two patients (Dronkers et al., 2007).

2.3.2 Is Broca’s Area an Anatomical Area Per Se?

Despite the general lack of consensus on what constitutes Broca’s area (Lindenberg et al., 2007), there is some agreement among researchers that this area is neuroanatomically associated with the pars opercularis (BA 44) and pars triangularis (BA 45) of the LIFG (Greenlee, Oya, Kawasaki, Volkov & Severson, 2007). Both the gross structure and the cytoarchitectonics of the LIFG are marked by interindividual variability. In addition, the two brain areas differ in their postnatal trajectories and there is evidence on differences in their respective functionalities. This has led some authors to conclude that Broca’s area is not an anatomical area per se (e.g., Hagoort, 2005).

Individual differences in the brain’s organization of language have been recognized at several levels: “in the gross anatomy of human left perisylvian cortex, … in the gyral pattern at the end of the sylvian fissure…, in the extent of the planum temporale … and in the extent of its specific cytoarchitectonic areas…” (Ojemann, 1991, p. 2283). Amunts and Zilles (2006) also point out the individual variability in cytoarchitectonic features. As an example, in a study by Amunts and her colleagues (1999) it was shown that volumes of BAs 44 and 45 differed in 20 post-mortem brains by a factor of 10, which is much larger when compared to interindividual differences found in other brain regions (*cf.* the hyppocampi volume in the same post-mortem brains differed only by a factor of 2).

Applying a quantitative and observer-independent cytoarchitectonic analysis of BAs 44 and 45, Amunts et al. (1999) found that BA 44 and BA 45 differed in granularity in layer IV: area 44 had “a barely recognizable dysgranular layer IV” (p. 325). More specifically, layer IV was visible, but it could not appear as a layer containing the granular cells exclusively, because it was invaded to different degrees by the pyramidal cells from the lower part of layer III and from the upper part of layer V. On the contrary, BA 45 “differed essentially from area 44 by the presence of a clearly visible layer IV” (*ibid*). Other differences between BAs 44 and 45 include left-larger-than-right volume of BA 44, but not of BA 45 (Amunts & Zilles, 2006), and a significant left-over-right asymmetry in cell density for BA 44, but not for BA 45 in adult brains (Amunts et al., 1999).

Furthermore, distinct postnatal developmental trajectories were also reported for BA 44 and BA 45. A study of 34 human brains has shown that asymmetry between the left and right BAs 44 and 45, which was established by the age of 1, tended to increase with age, reaching an adult-like asymmetry at the age of 5 in BA 45 and at the age of 11 in BA 44 (Amunts, Schleicher, Ditterich & Zilles, 2003).

Although the exact functional differences between BA 44 and BA 45 are still not known (Greenlee et al, 2007), the cytoarchitectonic differences between the pars opercularis and pars triangularis of the LIFG indicate that these areas' respective functionalities may differ to a greater extent than previously assumed. Amunts, Schleicher and Zilles (2004) compared the cytoarchitecture of BAs 44 and 45 of Mr. Emil Krebs, who spoke fluently more than 60 languages, with the cytoarchitecture of the same brain areas in 11 male control brains. They found statistically significant cytoarchitectonic differences between Krebs' and controls' left and right BA 44, and in right BA 45, while no significant difference was found when the cytoarchitecture of visual area BA 18 was compared between E.K.'s and the controls' brains. Thus, there is a relationship between the cytoarchitecture of BAs 44, 45 and language abilities.

2.3.3 Broca's Area is Not Dedicated Exclusively to Language

Following early work of Broca, the involvement of the LIFG in speech production has been confirmed by the evidence from numerous lesion studies associated with aphasia, and recently by neuroimaging evidence on neurologically intact populations (Hillis, 2007). Whereas Broca's area supports speech production, nonfluent speech may also result from a disconnection of Broca's area from the superior temporal cortex and damage to the insular white matter (Bonilha & Fridriksson, 2009).

The assumption that Broca's area is an exclusive motor center for speech has been challenged since the 1970s (Caramazza & Zurif, 1976; Mohr, 1976), due to the evidence on this area's involvement in comprehension of complex syntactic structures. Furthermore, a growing body of neuroimaging evidence suggests that this area is involved not only in syntax (Just et al., 1996; Stromswold et al., 1996; Caplan et al., 2000; Embick et al., 2000; Sakai, Noguchi, Takeuchi & Watanabe, 2002; Ben-Shachar et al., 2004), including artificial languages (Peterson, Forkstam & Ingvar, 2004), but also in language tasks that are not of syntactic nature,