CHAPTER 7

The Executive Functions in Language and Communication

CHAPTER OUTLINE

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DEFINING EXECUTIVE FUNCTIONS

The understanding of the role of the prefrontal cortex in behavior and cognition and the concept of executive functions have been developed through a series of progressive historical steps.

During the late nineteenth and early twentieth centuries, clinical investigators documented diverse behavioral disorders in cases of prefrontal lobe pathology. It was observed that prefrontal pathology did not result in any evident sensory or motor disturbance, but behavioral/personality changes were frequently found. Phineas Gage has become the most typical illustration of frontal lobe dysfunction and has significantly contributed to the understanding of the role of the frontal lobes in behavior. Harlow (1868) described Phineas Gage as a responsible foreman for a railroad company who suffered a tragic accident in which a tampering rod was projected through his frontal lobes. After this accident, profound personality changes were evident, and he was described as "no longer Gage" by associates who perceived his behavior as "profane," "irascible," and "irresponsible." It was of interest to Harlow that cognitive functions (i.e., memory, language, etc.) remained intact, whereas personality (manner of behaving) was so greatly altered. Phineas Gage has become one of the best known classical cases in the history of the neurosciences, and different papers have been devoted to its analysis (e.g., Damasio, Grabowski, Frank, et al., 1994; Macmillan, 2000, 2008).

In 1880 Herman Oppenheim coined the term *witzelsucht*, which was demonstrated by childishness and joking with "alleged" cheerfulness (Oppenheim, 1890, 1891). The term *moria* (reflecting "stupidity" and a jocular attitude) was part of the change they observed associated with damage in the prefrontal regions of the brain. Oppenheim's patients all had tumors involving

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right frontal areas, frequently invading the mesial and basal areas. Jastrowitz (1888) further noted unconcern and "inappropriate cheerfulness" associated with right frontal pathology.

The term "executive functions" is a relatively new term in the neurosciences, and until recently, the preferred term was "frontal lobe functions" (or "prefrontal functions"). "Frontal lobe syndrome" was conceptualized by Feuchtwanger in 1923. He correlated frontal lobe pathology to behaviors that were not related to overt speech, memory, or sensorimotor deficits. He emphasized the personality changes in motivation, affective dysregulation, and the incapacity to regulate and integrate other behaviors. During the following years, particularly during the 1980s and 1990s, a diversity of books specifically devoted to the analysis of frontal lobe syndrome were published (e.g., Fuster, 1989; Levin, Eisenberg & Benton, 1991; Miller & Cummings, 1998; Perecman, 1987; Pribram & Luria, 1973; Stuss & Benson, 1986).

Luria (1980) can be regarded as the direct antecessor of the term "executive functions." He distinguished three functional units in the brain: (1) arousal-motivation (limbic and reticular systems); (2) receiving, processing, and storing information (postrolandic cortical areas); and (3) programming, controlling, and verifying activity (frontal lobes). Luria mentions that this third unit has an executive role. Lezak (1983) used the term "executive functions" to discriminate cognitive functions from the "how" or "whether" of human behaviors. Lezak emphasized the fluid nature of executive functioning and how dependent the cognitive and emotional aspects of functioning were on the "executive." Baddeley (1986) grouped these behaviors into cognitive domains that included problems in planning, organizing behaviors, disinhibition, perseveration, reduced fluency, and initiation. Baddeley also coined the term "dysexecutive syndrome."

The definition of executive function is encompassed by actions fueled by conceptualizations, such as the ability to filter interference; control attention; engage in goal-directed behaviors; abstracting; problem-solving; metacognition; anticipate the consequences of one's actions; program motor behavior; inhibit immediate responses; regulate behavior verbally; reorient behavior according to behavioral consequences; perform temporal integration of behavior, personality integrity, and consciousness; and the adaptive concept of mental flexibility (Denckla, 1996; Fuster, 2001; Goldberg, 2001; Grafman, 2006; Luria, 1969, 1980; Miller & Cummings, 1998; Stuss & Benson, 1986; Stuss & Knight, 2002). The concept of morality, ethical behaviors, self-awareness, and the idea of the frontal lobes as manager and programmer of the human psyche are also included. Elliott (2003) defines executive functioning as complex processing requiring the coordination of several subprocesses to achieve a particular goal. Intact frontal processes, although not synonymous with executive functioning, are integral to its function.

Although executive functions depend on extended dynamic networks including different brain areas (Koziol & Budding, 2009), it is assumed that the prefrontal cortex plays a major controlling and monitoring role. Neuroimaging results have also implicated posterior, cortical, and subcortical regions in executive functioning (Roberts, Robbins, & Weiskrantz, 2002). Most importantly, the prefrontal cortex does not only participate in those classically recognized executive operations (sequencing, alternating, inhibiting, etc.), but it also plays a core role in coordinating cognition and emotion (Mitchell & Phillips, 2007). Interestingly, most of the disturbances reported in Phineas Gage (and in many cases of prefrontal syndromes) refer to behavioral/emotional disturbances; or more precisely, disturbances in coordinating cognition and emotion/motivation. As noted by Harlow (1868) cognitive functions in Phineas Gage remained intact. The prefrontal lobe has extensive connections to subcortical and limbic system areas (Barbas, 2006; Damasio & Anderson, 2003), and even its orbital portion could be regarded as an extension of the limbic system. Stuss and Alexander (2000) suggest that the most important role of the frontal lobes includes affective responsiveness, social behavior, and personality development. The frontal lobes, particularly the right lobe, have also been related with empathy in general and with "theory of mind"—the ability to attribute mental states to others—in particular (Platek, Keenan, Gallup, & Mohamed, 2004; Stuss, Gallup, & Alexander, 2001).

Currently, frontal lobe function research is utilizing functional brain imaging techniques to pool collateral findings, look at antecedents, and use a large sample size to eliminate spurious variables; thus, brain regions that contribute to dysexecutive syndromes may prove to be more multifunctional (Lloyd, 2000). Functional imaging has demonstrated that adults and children with focal, especially frontal right-hemispheric, lesions display similar behaviors such as attentional deficits, inability to inhibit a response, and impersistence of activity (Filley, Young, Reardon, & Wilkening, 1999).

Typically, executive functions are analyzed in experimental conditions using diverse research strategies, such as solving diverse problems, finding similarities between two words, providing an answer that requires inhibiting another, etc. A paradigm is created, and the subject is required to solve it. Brain activity can be recorded simultaneously, using brain electrical activity or recording the regional level of activation (e.g., Osaka et al., 2004). Alternatively, executive functions are analyzed in brain-damaged populations in order to find the contribution of different brain systems (e.g., Jacobs, Harvey, & Anderson, 2007). This last approach represents the classical neuropsychological method. Executive functions, however, are rarely analyzed in natural ecological conditions.

The Anatomy of the Frontal Lobes

Anatomically, the frontal lobes are the largest lobes of the brain. Laterally, they are anterior to the Rolandic fissure and superior to the Sylvian fissure. Medially, they extend forward from the Rolandic fissure and the corpus callosum. The frontal lobes include (a) the posterior regions of the frontal cortex (agranular frontal cortex), associated with motor activity. They correspond to the primary motor area (Brodmann's area —BA—4, or the precentral gyrus), on one hand; and the premotor area (or motor association area: BA6, 8—frontal eye field, and BA44—Broca's area), on the other. And (b) the prefrontral cortex (or granular frontal cortex), corresponding to BA9, 10, 11, 12, 24, 32, 45, 46, and 47, as illustrated in Figure 7-1. The prefrontal cortex is usually subdivided into the dorsolateral, mesial, and orbital regions. The limbic components of the frontal lobe include the anterior cingulum and the posterior section of the frontal orbital cortex (Damasio & Anderson, 2003; Fuster, 2008; Mesulam, 2002).

The frontal lobe increases in size throughout phylogenetic evolution. Given the overall size of the human brain, the entire frontal lobe of humans is approximately as large as expected for a primate brain (Semendeferi, Lu, Schenker, & Damasio, 2002), yet two portions of the frontal lobe (the primary motor and premotor areas) are significantly smaller; consequently, the prefrontal area is larger than expected (Schoenemann, 2006). The human prefrontal cortex is much larger than that in pongids (chimpanzees, gorillas, and orangutans): 12.7% of total brain volume, compared with an average of 10.3% for pongid species. Differences are observed in the white matter rather than in the gray matter. Comparing humans (brain size about 1350 cm^2) with chimpanzees (brain size about 311 cm^2), prefrontal gray volumes are 4.8 times larger in humans, whereas nonprefrontal gray volumes are only 4.2 times larger. However, prefrontal white volumes are about 5.0 times larger in humans, whereas nonprefrontal white volumes are only 3.3 times larger (Schoenemann, Sheehan, & Glotzer, 2005).

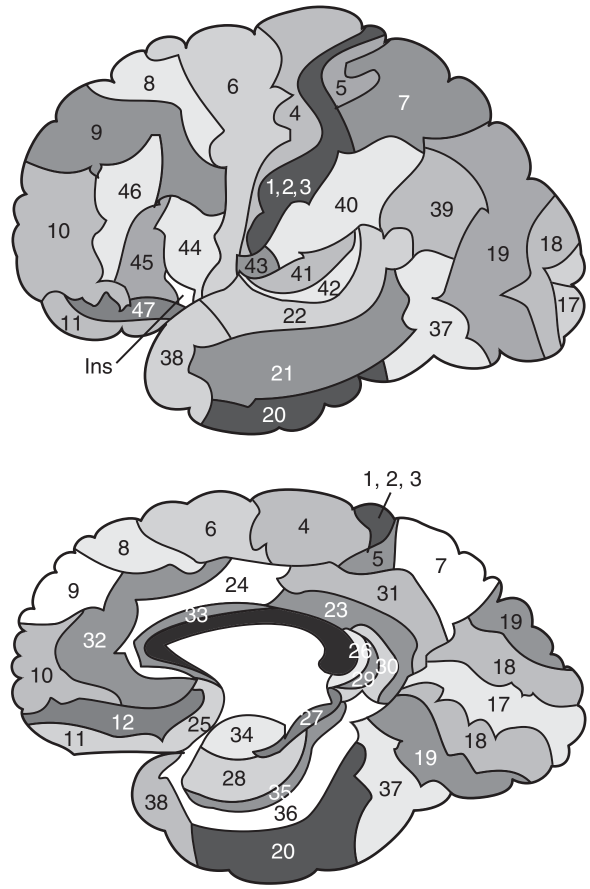

Figure 7-1 Brodmann's areas. Prefrontal cortex corresponds to areas 9, 10, 11, 12, 24, 32, 45, 46, and 47. [Adapted from B. Bernal & J. Perdomo (2007). Brodmann's interactive atlas 1.1. http://www.fmriconsulting.com/brodmann/]

The prefrontal areas of the frontal lobes can be regarded as association areas or intrinsic cortical areas. Luria (1980) considers that the prefrontal regions correspond to tertiary areas (which participate in processing information of various types) of the cerebral cortex. The prefrontal lobes maintain extensive connections, particularly with other cortical areas, the limbic system, the cortical and subcortical motor areas, and the sensory cortex.

Intracortical Connections

The major cortical connections are established with the visual, auditory, and somatosensory cortexes. The prefrontal cortex is also connected with the premotor cortex, and through this, with the primary motor cortex. Some projections are unidirectional (e.g., the caudate nucleus and the putamen); and others appear to be bidirectional (e.g., the dorsomedial nucleus of the thalamus) (Damasio & Anderson, 2003). There are multiple intracortical connections, including the superior longitudinal fasciculus—the main bundle of fibers between the posterior and anterior regions of the cerebral cortex. The uncinate fasciculus connects the anterior temporal lobe with the frontal lobe. The orbitofrontal limbic and mesial frontal cortexes receive projections from the superior temporal gyrus, and the orbitofrontal region receives projections from the inferior temporal cortex. The cingulum connects the frontal lobe with the parahippocampal gyrus. The arcuate fasciculus borders the insula and connects the inferior frontal and medial gyri with the temporal lobe. The occipitofrontal fasciculus extends posteriorly from the frontal lobe to the temporal and occipital lobes (Figure 7-2).

Subcortical Connections

According to Damasio and Anderson (2003), it is possible to distinguish the following types of fronto-subcortical connections:

Projection From the Hypothalamus

Although no direct connections between the hypothalamus and the prefrontal cortex seem to exist, there have been signs of indirect connections, particularly through the thalamus.

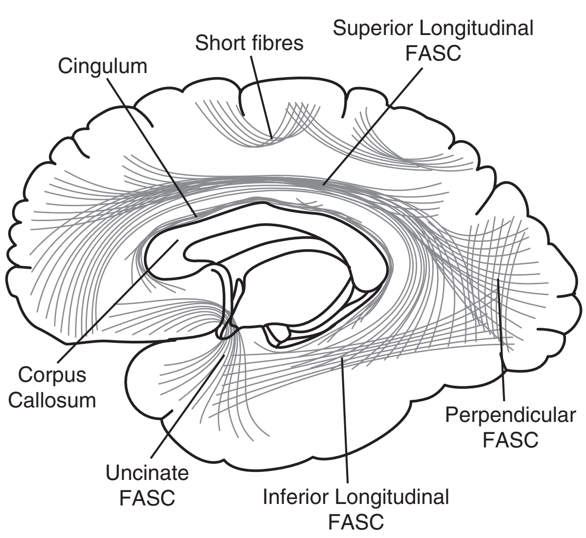

Figure 7-2 Intracortical connections of the frontal lobe. [Adapted from http://human.freescience.org/images/wikimages/250px-Gray751.png]

Projections From the Amygdala and Hippocampus

There have been signs of some projections toward the mesial aspects of the frontal lobe, particularly to the gyrus rectus and the subcallosal and anterior portions of the cingulum.

Projections From the Thalamus

The projections from the thalamus are primarily directed from the dorsolateral nuclues of the thalamus toward the orbital frontal cortex. Other additional connections have been discrete, as is the projection from the medial pulvinar nucleus to BA8.

Projections to the Amygdala and Hippocampus

Direct connections exist as do indirect connections through the cingulum and the uncinate fasciculus.

Projections to the Thalamus

These projections move toward the dorsal medial nucleus, the intralaminar nuclei, and the pulvinar.

Projections to the Hypothalamus

These projections are nuclear, probably through the mesencephalon and the periaquaductal gray matter.

Projections to the Striatum

Projections to the caudate nucleus and putamen have been identified. Especially important are the projections from the cingulum and the supplementary motor area (SMA), which are related to the motor control system of the brain.

Projections to the Claustrum, Subthalamic Region, and Mesencephalon

These projections go through the uncinate fasciculus and the external capsule. They originate primarily in the orbital and inferior dorsolateral regions.

In summary, the prefrontal cortex has extensive connections with the rest of the cerebral cortex, as well as with the limbic system, the basal ganglia, the thalamus, and other brain areas.

Some disagreement exists around the question of whether or not there is a single unitary factor accounting for the diversity of executive functions (e.g., Grafman, 2006; Kimberg, D'Esposito, & Farah, 1997; Stuss & Alexander, 2007). Friedman and colleagues (2008) found that executive functions are highly correlated, suggesting a common factor that goes beyond general intelligence. These authors concluded that executive functions represent one of the most heritable psychological traits. It is not evident, however, what the particular unitary factor saturating the different executive function tests could be. Some different proposals and interpretations have been presented during recent years.

Behavior inhibition has been considered as a potential candidate for the single factor responsible for successful performance in different executive tests (Barkley, 1997) alone or in combination with working memory (Pennington & Ozonoff, 1996). Salthouse (1996, 2005), on the other hand, suggested that reasoning and perceptual speed represent the underlying factors related to all executive functions. Salthouse (2005) observed that performance on two common tests of executive functioning, the Wisconsin Card Sorting Test and the Controlled Oral Word Association Test, were strongly correlated with reasoning ability and perceptual speed.

Other researchers challenge the existence of such a unitary factor. Thus, some authors have emphasized that certain frontal lobe patients perform well on some tests purported to assess executive abilities but not on others (Godefroy, Cabaret, Petit-Chenal, et al., 1999). Furthermore, it has been reported that correlations among different executive tests are frequently moderate or low and very often lack statistical significance (Salthouse, Atkinson, & Berish, 2003).

Some other investigators have taken an intermediate position. For instance, Miyake, Friedman, Emerson, et al. (2000) studied three often-postulated aspects of executive functions (shifting, updating, and inhibition) and concluded that, although these functions are clearly distinguishable, they do share some underlying commonality. Based on the results of their study, the authors stated that executive functions are "separable but moderately correlated constructs" thus suggesting both unitary and nonunitary components of the executive system. By the same token, several authors have suggested different subcomponents of executive functions (e.g., Anderson, 2001; Delis, Kaplan, & Kramer, 2001; Denckla, 1994; Elliott, 2003; Hobson & Leeds, 2001; Lafleche & Albert, 1995; Piguet et al., 2002). Thus, Stuss and Alexander (2007) refer to three separate frontal attentional processes within the executive category: energization (superior medial), task setting (left lateral), and monitoring (right lateral). Clinical and experimental research has converged to indicate the fractionation of frontal subprocesses and the initial mapping of these subprocesses to discrete frontal regions (Stuss & Levine, 2002). Factor analysis has also supported that executive functions include several subcomponents (Mantyla, Carelli, & Forman, 2007; Stout et al., 2003).

Major Dysexecutive Syndromes: Normal and Abnormal Conditions

Most frequently, three different prefrontal syndromes associated with specific disturbances in executive functions are separated (Box 7-1).

Box 7-1

Three Major Prefrontal Syndromes

DORSOLATERAL SYNDROME

Impaired set shifting (stuck-in set perseveration)
Depression
Rigidity
Concreteness
Verbal-action dissociation
Impersistence
Verbal dysfluency (left)
Design dysfluency (right)
Poor problem-solving abilities
Poor motor programming
Poor planning
Working memory deficits
Spontaneous recall poorer than recognition

MEDIODORSAL SYNDROME

Mutism
Apathy
Slowness
Amotivation
Poor task maintenance
Abulia/decreased motor activity
Transcortical motor aphasia (left)
Aspontaneity
Impaired generative cognition
Reduced affect
Poor humor appreciation (right)
Akinetic mutism (bilat)

ORBITOFRONTAL SYNDROME

Sensitivity to interference
Euphoria/mania
Poor decision making
Impulsiveness
Theory of mind deficits
Disinhibition
Social and moral reasoning impairment
Jocularity
Stuck-in-set perseveration (on object alternation)
Irresponsibility
Inappropriateness
Tactlessness
Impaired social judgment

Adapted from Chayer, C., & Freedman, M (2001). Frontal lobe functions. *Current Neurology and Neuroscience Reports, 1*, 547–552.

Dorsolateral Syndrome

Cummings (1993) indicated that the dorsolateral circuit is the most important to executive functioning. The most noted deficit is an inability to organize a behavioral response to novel or complex stimuli. Symptoms are on a continuum and reflect the capacity to shift cognitive sets, engage existing strategies, and organize information to meet changing environmental demands. Dysfunction in this region disrupts essential component cognitive processes, including working memory and inhibitory control (Anderson & Tranel, 2002). Various researchers, including Luria (1969), have noted preservation, stimulus-bound behavior, echopraxia, and echolalia. According to Fuster (1997, 2002), the most general executive function of the lateral prefrontal cortex is temporal organization of goal-directed actions in the domains of behavior, cognition, and language. Lateral differences are observed: whereas left prefrontal damage is more directly associated with cognitive processes, right damage is associated with both restriction of affect and emotional dyscontrol and defects in the perception or comprehension of emotional information. Anosognosia, impaired empathy, and defects in the appreciation of humor (Shammi & Stuss, 1999) are also found. Following lesion to the right dorsolateral area, a transcortical motor aprosodia is expected, whereas a left-sided dorsal lesion will produce a decline in verbal fluency on word-generation tasks and so-called extrasylvian (transcortical) motor aphasia.

A hierarchical model of prefrontal function has been proposed in which dorsolateral and frontopolar regions are serially recruited in a reasoning or memory task that requires evaluation of internally generated information: whereas the dorsolateral prefrontal cortex is involved when externally generated information is being evaluated, the frontopolar area becomes recruited when internally generated information needs to be evaluated (Christoff & Gabrieli, 2000).

Medial Frontal Lobe

The anterior cingulate is the origin of the anterior cingulate-subcortical circuit. Goldman-Rakic and Porrino (1985) identified input from BA24 to the ventral striatum, which includes the ventromedial caudate, ventral putamen, nucleus accumbens, and olfactory tubercle. Damage to these circuits causes apathy or abulia (a severe form of apathy). Acute bilateral lesions in the medial frontal area can cause akinetic mutism, in which the individual is awake and has self awareness but does not initiate behaviors. These patients demonstrate diminished drive. The spectrum can range to the extreme following bilateral lesions (i.e., patients can be profoundly apathetic, may rarely move, may be incontinent, may eat only when fed, and may speak only in monosyllables when questioned). They are not emotionally reactive, even with painful stimuli, and appear completely indifferent (Damasio & Damasio, 1989). Subcortical deficits, as seen with Parkinson disease and Huntington disease as well as thalamic lesions, may cause apathy if the anterior cingulate is affected.

Orbitofrontal Syndrome

Orbitofrontal syndrome has been associated with disinhibition, inappropriate behaviors, irritability, mood lability, tactlessness, distractibility, and loss of import to events. Affect may become extreme with *moria* (an excited affect) or *Witzelsucht* (the verbal reiteration of caustic or facetious remarks), first noted by Oppenheim (1890, 1891). Individuals with this syndrome are unable to respond to social cues, and they are stimulus bound. Cummings (1993) noted that automatic imitation of the gestures of others may occur with large lesions. Interestingly, it has been noted that these patients have no difficulty with card-sorting tasks (Laiacona et al., 1989). Eslinger and Damasio (1985) coined the term "acquired sociopathy" to describe dysregulation that couples both a lack of insight and remorse regarding these behaviors. Much of this may reflect the stimulus-bound nature of this disorder. The orbitofrontal cortex appears to be linked predominantly with limbic and basal forebrain sites. The orbital prefrontal cortex may have the ability to maintain its own level of functional arousal due to its cholinergic innervation from the basal forebrain (Mesulam, 1986). According to Fuster (2002), the ventromedial areas of the prefrontal cortex are involved in expression and control of emotional and instinctual behaviors.

The three major prefrontal syndromes could be grouped into two. Ardila (2008) suggested that the prefrontal lobe participates in two closely related but different executive function abilities: (1) "metacognitive executive functions": problem solving, planning, concept formation, strategy development and implementation, controlling attention, working memory, and the like, which are related with the activity of the dorsolateral prefrontal cortex; and (2) "emotional/motivational executive functions": coordinating cognition and emotion/motivation (that is, fulfilling biological needs according to some existing conditions), which are related with the orbitofrontal and medial frontal cortexes. Ardila (2008) suggested that "metacognitive" and "emotional/motivational" executive functions may have presented different evolutionary patterns during human phylogeny; and while primates and hominids may possess the second, the first one is only observed in recent human evolution.

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In the prefrontal cortex, as in other cortical areas, lateralization is observed. Language-related disturbances (such as extrasylvian or transcortical motor aphasia) are more frequently found in cases of left frontal pathology, whereas social, spatial, and, in general, non–language-related disturbances are usually associated with right hemisphere damage. Goldberg (2001) describes two types of cognitive control: one guiding behavior by internal cues and the other by external cues. Normally operating in concert, damage to the frontal lobes can result in perseveration (disinhibited repetition) due to the following: diminished ability to switch behaviors in response to changing demands and environmental dependency, and inability to generate behaviors that are guided and personal. The left prefrontal system is thought to subserve the guiding of cognitive selection by working memory and internal contingencies, whereas the right prefrontal area mediates guiding cognitive selection by external environmental contingencies.

Even though executive dysfunction that follows focal brain injury most often occurs (or is most severe) following frontal lobe injury, not all executive processes are exclusively sustained by the frontal cortex (Andres & Van der Linden, 2002). Lesions in nearly any part of the brain have been associated with executive dysfunction (Hausen, Lachmann, & Nagler, 1997). Contemporary research even finds strategy operations in the occipital cortical neurons on visual tasks (Super, Spekreijse, & Lamme, 2001). Andres (2003) analyzed two executive processes: inhibition and dual-task management. He concluded that (1) executive processes involve links between different brain areas, not exclusively with the frontal cortex, (2) patients with no evidence of frontal damage may present with executive deficits, and (3) patients with frontal lesions do not always show executive deficits.

Communication Disorders in Frontal Lobe Pathology

A diversity of disorders in communication ability can be observed in cases of frontal lobe pathology including dysarthria, aphasia, language pragmatic disturbances, metalinguistic skill abnormalities, and verbal reasoning impairments. Complex and conceptual verbal abilities may be significantly impaired (Novoa & Ardila, 1987). Most frequently these disorders are found in cases of left hemisphere pathology. The idiosyncrasies of the disorders depend on the specific location and extension of the damage. Alexander, Benson, and Stuss (1989) proposed a comprehensive classification of communication disorders observed in frontal lobe pathology (Table 7-1).

Left Hemisphere Pathology

Aphemia

Aphemia was the initial name used by Broca to refer to the impairment in language production associated with left posterior frontal damage (Broca, 1861), but this name was later replaced with aphasia by Trousseau in 1864. The term aphasia prevailed and aphemia was forgotten. During the following decades, the term aphemia appeared from time to time in the neurological literature to refer to the articulatory defects associated with Broca's aphasia. Schiff, Alexander, Naeser, and Galaburda published an influencial paper in 1983 reacquiring the term aphemia to name the dysarthria following the appearance of left frontal-lobe lesion, including the pars opercularis, inferior prerolandic gyrus (cortical dysarthria), or the white matter deep to those regions. Today, this is the most frequent use of the term aphemia: Aphemia is the spastic dysarthria observed in cases of damage of the upper motor neuron in the pyramidal system. This dysarthria is usually associated with Broca's aphasia, and it is also observed in cases of damage involving the internal capsule.

Table 7-1 Communication Disorders Associated With Frontal Lobe Pathology

	LEFT HEMISPHERE	RIGHT HEMISPHERE
Lower motor cortex and posterior operculum	Aphemia	Dysprosody
Full operculum plus lower motor cortex	Broca's area aphasia	Dysprosody
Dorsolateral frontal	Transcortical motor aphasia	Defective pragmatic discourse
Medial frontal	Mutism	Decreased output
Prefrontal	Reduced formulation; impoverished discourse	Disordered formulation; tangential discourse; confabulation

Adapted from Alexander, M. P., Benson, D. F., & Stuss, D. T. (1989). Frontal lobes and language. *Brain and Language, 37*, 656–691.

In cases of damage of the lower motor cortex and the posterior operculum, the observed clinical syndrome is quite consistent. Initially, the patient is mute and often hemiparetic, but both conditions rapidly improve. Lower facial paresis may persist. Language function is intact or minimally impaired. Speech is slow and effortful, and dysarthria is observed. Long-term sequelae are variable, but most often language recovers to a normal status though dysarthria remains.

Broca's Aphasia

Broca's aphasia (named by Luria as efferent or kinetic motor aphasia) is characterized by nonfluent expressive language that is poorly articulated and consists of short phrases that are agrammatical and produced with great effort. The expressive language basically consists of nouns with a marked deficiency or absence of syntactic structure and affixes (agrammatism). The motor-articulatory defect has been called a variety of names, but the most frequently used term is apraxia of speech.

The level of language comprehension is always superior to verbal production, although never normal, especially in relation to grammatical comprehension. Patients with Broca's aphasia easily identify objects or body parts, but if they are asked to name multiple objects or body parts in a particular order, the patients only manage to do so at a level of about two or three words. Similarly, they produce obvious errors in the comprehension of grammatical structures of language. However, the deficit in grammatical production is more severe than their defect in comprehension.

Language repetition is inadequate, and there is a presence of phonetic deviations, phonologic paraphasias, simplifications of syllabic groups, and iterations. Despite this difficulty, repetitive language may be superior to spontaneous language. Interestingly, there is a selective defect seen in the repetition of grammatical structure also absent in spontaneous language. For example, when a patient is asked to repeat, "*the boy walks on the street*," he/she may only be able to repeat, "*boy walk street*," omitting the elements with a purely grammatical function. Occasionally, the patient only manages to repeat nominative elements (e.g. "*boy, street*").

The production of automatic series (counting, days of the week, etc.) is superior to spontaneous language. Singing also frequently improves verbal production in these patients; nevertheless, there is little generalization between singing or automatic language and spontaneous production.

Pointing and naming are always deficient though pointing is superior to naming. If syntactic comprehension is excluded, ("*the dog bites the cat,*" "*the cat bites the dog*"), linguistic comprehension can occasionally appear practically normal. During naming, however, it is common to find articulatory difficulties (phonetic deviations) that can appear as phonological paraphasias, as well as omissions and phonological simplifications. The presentation of phonological cues can help initiate articulation. Similarly, the completion of high-probability phrases ("*I write with a* ____) can lead to a correct production of the desired name.

It is usually recognized that Broca's aphasia has two different distinguishing characteristics: (a) a motor-articulatory component (lack of fluency, disintegration of speech kinetic melodies, verbal-articulatory impairments, etc.) that is usually referred to as *apraxia of speech*; and (b) agrammatism (e.g., Benson & Ardila, 1996; Berndt & Caramazza, 1980; Goodglass, 1993; Kertesz, 1985; Luria, 1976). Indeed, a large part of the frontoparietotemporal cortex has been observed to be involved with syntactic-morphological functions (Bhatnagar, Mandybur, Buckingham, & Andy, 2000). Apraxia of speech has been specifically associated with damage in the left precentral gyrus of the insula (Dronkers, 1996; but see, Hillis et al., 2004).

Noteworthy, it seems evident that the lesions limited strictly to Broca's area are not sufficient to cause the complete syndrome; in the case of injuries limited specifically to Broca's area, usually one can observe only slight defects in articulatory agility, a certain "foreign accent," grammatical simplifications with sporadic grammatical errors, the use of short phrases in the expressive language, and a reduced ability to find words. Hemiparesis is usually minimal. This restricted form of Broca's aphasia could also be named *Broca's area aphasia* (or *minor Broca's aphasia,* or *type I Broca's aphasia*). The extensive form or the complete syndrome of Broca's aphasia is observed only if the damage extends additionally to the opercular region, the precentral gyrus, the anterior insula, and the paraventricular (at the side the ventricles) and periventricular (around the ventricles) white matter. This form of Broca's aphasia can be called *extended Broca's aphasia* (or *type II Broca's aphasia).*

Transcortical (Extrasylvian) Motor Aphasia

Different names have been applied to nonfluent aphasia with preserved repetition and good comprehension, including dynamic aphasia (Luria, 1980) and anterior isolation syndrome (Benson & Geschwind, 1971), but the most frequent name is transcortical (or extrasylvian) motor aphasia. However, the term transcortical motor aphasia has been used to refer to two different language disorders: lack of verbal initiative associated with left prefrontal pathology (Luria's dynamic aphasia) and defects in language initiation observed in cases of damage in the left SMA (Ardila & Lopez, 1984). The initial mutism observed in cases of medial frontal pathology can be followed by language initiation disturbances associated with nearly normal repetition. This language defect corresponds to the aphasia of the left SMA (Alexander et al., 1989).

Transcortical motor aphasia associated with dorsolateral lesions could be interpreted as "dysexecutive aphasia" and will be analyzed later in this chapter.

Mutism

Mutism refers to the inability or unwillingness to speak. Akinetic mutism is a variety of mutism characterized by an inability to both speak and to carry out purposeful movements, regardless if the patient lies with eyes open. Mutism has been related with frontal mesial pathology involving the cingulate gyrus. Paresis may occur, and weakness is greater in the leg than in the arm. Sometimes, unilateral akinesia or hypokinesia may be observed.

Reduced Verbal Production

Reduced verbal production can be considered one of two distinctive elements of left prefrontal lesions, and it is characterized by a loss or reduction of spontaneous language, difficulty organizing expressive language (i.e., converting ideas or intentions in expressive language), poor verbal generation, and defects in verbal reasoning. More exact defects of the paralinguistic type have been found, impairing the way in which language is formulated, controlled, and structured.

Nevertheless, lesions limited to the polar region are not associated with apparent defects in language; instead, they are associated with personality changes, including apathy and irritability.

Right Hemisphere Pathology

Dysprosody

Damage in the right lower motor cortex and the posterior operculum results in so-called affective motor dysprosody, characterized by difficulties in using the melodic contours in verbal output (Ross, 1981). Speech is flat and is without the appropriate prosodic quality. This difficulty can be observed not only when speaking but also when singing. Patients may have difficulties in conferring the emotional background of communication: sadness, irony, sarcasm, happiness, etc.

Defective Pragmatic Discourse

Disturbances in the pragmatic aspects of communication are found in cases of extensive right frontal dorsolateral lesions. These patients may have a significant difficulty in organizing a coherent narrative. Irrelevant and tangential comments are frequent, and they often speak using a free-ideas association (Ardila, 1984). They have difficulties interpreting analogies, ironies, and general, figurative language. These patients may have a concrete, blunt, and impolite discourse.

Decreased Output

Patients with lesions limited to the medial right frontal lobe (including the SMA) have a reduction in language production. Prosody is also frequently reduced. According to Alexander et al. (1989), the main difference between patients presenting left and right mesial lesions is quantitative rather than qualitative. In both cases there is a reduction in verbal output, but the reduction is mild to moderate in cases of right lesions and significant in cases of left frontal lesions. However, in cases of right damage, prosody is also affected.

Disordered Verbal Formulation

Extensive right medial frontal damage is associated with significant behavioral abnormalities: emotional flattening, inappropriate and frequently vulgar behavior, apathy, and confabulation. These patients have difficulties in selecting a socially acceptable language. They tend to impulsively respond to their first associations; perseveration is not unusual, and confabulation associated with disorganized narrative in discourse is frequently observed (Alexander et al., 1989).

Frontal Lobe Language Areas: Contemporary Neuroimaging Studies

Contemporary neuroimaging studies have significantly advanced our understanding of the role of the frontal lobe in language. These studies have supported the notion that language areas in the human brain involve a network of regions, not only in the frontal lobe, but also in the temporal and parietal lobes of the left hemisphere (e.g., Binder et al., 1997; Calandra-Buonaura et al., 2002). Evidently, the frontal lobe has a major and controlling role in language, and using fMRI and PET techniques, it has been observed that the performance of a diversity of verbal tasks results in changes of the activation level in different frontal areas. These functions are described next following the organization of Brodmann's areas (see Figure 7-1).

Brodmann's Area 6 (Lateral Premotor Cortex Area, Including the Supplementary Motor Area)

According to functional studies, Brodmann's area 6 (BA6) participates in a diversity of functions. Its basic function, however, seems to be motor sequencing and planning movements (Schubotz & von Cramon, 2001). Damage in the lateral premotor area results in kinetic

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apraxia. The SMA portion is related with movement initiation; the left SMA also participates in language initiation and maintenance of voluntary speech production (Basho, Palmer, Rubio, et al., 2007; De Carli et al., 2007). Linguistic functions of left BA6 are diverse, but a major function evidently is speech motor programming (Fox et al., 2000; Shuster & Lemieux, 2005); Broca's area indeed corresponds to a subdivision of the premotor cortex, and some of the linguistic functions of the lateral premotor area are probably the result of an extended activation of the frontal languages areas. Participation of BA6 in memory, attention, and executive functions (Burton, Noll, & Small, 2001; Fincham, Carter, van Veen, et al., 2002) may be due to the activation of an extended brain network, which sometimes involves BA6. The existence of mirror neurons that activate when observing (and imagining) actions plays an important role in understanding, thinking, and planning (Morin & Grèzes, 2008).

Brodmann's Area 44 (Broca's Area, Inferior Frontal Gyrus, Pars Opercularis)

From the traditional point of view, Broca's area corresponds to BA44, but several contemporary authors also include BA45 (e.g., Foundas, Eure, Luevano & Weinberger, 1998).

Different proposals have been presented to explain language disturbances in so-called Broca's aphasia; several hypotheses have attempted to postulate a core BA44 function, including binding the elements of the language, selecting information among competing sources, generating/extracting action meanings, sequencing motor/expressive elements, acting as a cognitive control mechanism for the syntactic processing of sentences, constructing higher parts of the syntactic tree in speech production, and participating in verbal working memory (Ardila, 2010). Although the core functions of BA44 remain elusive, fluency and sequencing may potentially account for many of the functions in which BA44 participates (Abrahams et al., 2003; Amunts et al., 2004; Heim, Eickhoff, & Amunts, 2008).

The suggestion that BA44 includes mirror neurons for expressive movements is particularly provocative and may enlighten the question of inner speech (e.g., internally generated language) (Lawrence et al., 2006; Lotze et al., 2006; Manthey, Schubotz, & von Cramon, 2003). Unfortunately, just a few studies have analyzed the clinical disturbances associated with right BA44 from the perspective of the lesional model (Ardila, 2004). Functional studies have also disclosed the participation of BA44 in a diversity of tasks that are difficult to interpret with our current understanding of the brain, such as pain anticipation, perception of tactile stimulation, motion after-effect, object manipulation, smelling familiar odors, and music enjoyment; in those cases, BA44 activation is just an additional element in a complex brain network. It may be suggested that some internal verbalization can account for BA44 involvement in these unexpected activities. Its participation in working memory (Rämä et al., 2001) may also reflect the internal rehearsal of the information.

Brodmann's Area 45 (Broca's Area, Inferior Frontal Gyrus, Pars Triangularis)

According to contemporary neuroimaging studies, the functions of BA45 are significantly coincidental with the functions of BA44 (see http://www.fmriconsulting.com/brodmann/), supporting the proposal that they both, at least partially, correspond to a single brain system. Nonetheless, BA45 seems to be involved in relatively more complex verbal functions, for instance, processing of metaphors (Rapp, Leube, Erb, et al., 2004; Shibata, Abe, Terao, & Miyamoto, 2007) and reasoning processes (Goel, Gold, Kapur, & Houle, 1997, 1998). As observed with BA44, BA45 participates in a diversity of functions difficult to interpret with our current understanding of the brain (e.g., smelling of familiar odors) and probably reflects some inner speech during the performance of those tasks. BA45 participation in working memory (Rämä et al., 2001; Ranganath, Johnson, & D'Esposito, 2003) may also reflect the internal rehearsal of the information.

Brodmann's Area 8 (Part of Prefrontal Cortex; Lateral and Medial Supplementary Motor Area)

BA8 is usually regarded as the "frontal eye field." However, functional studies report that BA8 participates in a wide diversity of functions, including motor (Perry et al., 1999), language (Fox et al., 2000), executive functions (Crozier et al., 1999; Kübler, Dixon, & Garavan, 2006), memory (Rämä et al., 2001), and attention (Cheng, Fujita, Kanno, et al., 1995). Indeed, few studies refer to its participation in eye movements (horizontal saccadic eye movements) (Anderson et al., 1994; Miki, Nakajima, et al., 1996). It is very interesting to note the participation of the SMA in motor learning supported by several studies (Brunia, de Jong, van den Berg-Lenssen, & Paans, 2000; Inoue et al., 2000; Matsumara et al., 2004). Usually it is accepted that the SMA participates in initiating, maintaining, coordinating, and planning complex sequences of movements performed in a particular order. Stimulation of the left SMA has been related to arrest of speech and its damage to a particular type of language disorder referred as "aphasia of the SMA" (initial mutism lasting about 2–10 days; virtually total inability to initiate speech; nearly normal speech repetition; normal language understanding; and absence of echolalia). BA8 also participates in memory processes, particularly in verbal working memory (Rämä et al., 2001).

Brodmann's Areas 9 and 10 (Part of the Prefrontal Cortex, Middle Frontal Gyrus)

BAs 9 /10 have a significant participation in memory, particularly memory encoding, memory retrieval, and working memory (Pochon et al., 2002; Raye, Johnson, Mitchell, et al., 2002; Zhang, Leung, & Johnson, 2003). BAs 9/10 also have other evident executive functions, such as "executive control of behavior" (Kübler et al., 2006), "inferential reasoning" (Knauff, Mulack, Kassubek, et al., 2002), and "decision making" (Rogers et al., 1999). Their participation in complex language processes may suggest the use of verbal strategies in executive processing; in these cases (e.g., syntactic processing, metaphor comprehension, generating sentences, etc.) (Brown, Martinez, & Parsons, 2006; Shibata et al., 2007; Wang et al., 2008), an extensive network is activated, involving diverse language related areas.

Brodmann's Area 46 (Anterior Middle Frontal Gyrus)

The participation of the left anterior middle frontal gyrus in language (e.g., verbal fluency (Abrahams et al., 2003) and phonological processing (Heim, Opitz, Müller, & Friederici, 2003)) is shared by other left prefrontal convexital areas. According to current knowledge of language disturbances associated with brain pathology, other linguistic functions potentially related with BA46, such as verbal initiative and language pragmatics, have not been fully approached in fMRI studies.

Brodmann's Area 47 (Inferior Frontal Gyrus, Pars Orbitalis)

A significant amount of language-related functions have been associated with BA47, including semantic processing (De Carli et al., 2007), phonological processing (De Carli et al., 2007), semantic encoding (Li et al., 2000), and selective attention to speech (Vorobyev et al., 2004). In these cases, BA47 is simply one of the multiple steps in the brain language processing network. It could be further speculated that in these verbal related functions, the inferior frontal gyrus may play a more emotional/motivational function. Moreover, anatomically, BA47 is adjacent to BA45, an evident language brain area. BA47 also participates in some clearly emotionally related activities—e.g., adverse emotional inhibition (Berthoz, Armony, Blair, & Dolan, 2002) and in executive functions—e.g., deductive reasoning (Goel, et al., 1998).

Brodmann's Area 11 (Gyrus Rectus)

No language functions have been explicitly related with BA11. From the clinical perspective, it is usually assumed that BA11 (base of the frontal pole) is related with something that could be termed "personality integrity." Personality changes observed in individuals with a traumatic brain injury are thought to result from damage of this orbital frontal area. It could be conjectured that BA11 participates in some individuals' "style of reacting" or "emotional idiosyncratic style."

Brodmann's Areas 24 and 32 (Anterior Cingulated Gyrus)

The cingulate gyrus is part of the limbic system and hence has a direct participation in emotional behavior. Anterior cingulate gyrus damage can be associated with mutism and akinesia. Contemporary fMRI studies support its involvement in language initiative (e.g., Nathaniel-James, Fletcher, & Frith, 1997).

Table 7-2 summarizes the participation of different frontal areas in language and communication, according to Contemporary neuroimaging studies.

The Role of Broca's Area in Language and Cognition

In the past decade there has been a significant interest in reanalyzing the function of Broca's area (e.g., Grodzinky & Amunts, 2006; Hagoort, 2005; Thompson-Schill, 2005). From the traditional point of view, Broca's area

Table 7-2 Participation of Different Frontal Areas in Language and Communication, According to Contemporary Neuroimaging Studies

Brodmann's Area	Participation in Language and Communication
Area 6	left supplementary motor area: language initiation speech motor programming
Area 44 (and 45)	Praxis of speech and grammar
Area 8	Sequencing movements in a particular order
Areas 9 and 10	Complex language processes
Area 46	Verbal fluency, phonological processing
Area 47	Semantic and phonological processing; attention to speech
Area 11	No evident language function
Areas 24 and 32	Verbal initiative

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corresponds to BA44, but several contemporary authors also include BA45. In the traditional aphasia literature, it was assumed that damage in Broca's area was responsible for the clinical manifestations observed in Broca's aphasia. Only with the introduction of the computed tomography scan did it become evident that the damage restricted to Broca's area was not enough to produce the "classical" Broca's aphasia; extension to the insula, lower motor cortex, and subjacent subcortical and periventricular white matter is required (Alexander, Naeser, & Palumbo, 1990). "Broca's area aphasia" ("minor Broca's aphasia") is characterized by mildly nonfluent speech, relatively short sentences, and mild agrammatism; phonetic deviations and a few phonological paraphasias can be observed (Mohr et al., 1978); some foreign accent can also be noticed (Ardila, Rosselli, & Ardila, 1988).

Simultaneously including both BA44 and BA45 in Broca's area is problematic. BA44 is a premotor dysgranular area, whereas BA45 has a granular layer IV and belongs to the heteromodal prefrontal lobe (granular cortex) (Mesulam, 2002). So, from a cytoarchitectonic point of view, BA44 and BA45 are quite different. BA44 is a premotor area, whereas BA45 corresponds to the prefrontal cortex. From the aphasia perspective, some authors have referred to different clinical manifestations associated with damage in BA44 (Broca-type aphasia) and BA45 (transcortical motor/dynamic aphasia) (e.g., Luria, 1976). Some authors have also pointed out that indeed Broca's area is a collective term that can be fractionated into different subareas (Lindenberg, Fangerau & Seitz).

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Hagoort (2005, 2006) refers to the "Broca's complex" as including BA44 (premotor), as well as BA45 and BA47 (prefrontal cortex) (Figure 7-3). He argues that the Broca's complex is not a language specific area and that it becomes active during some non-language activities, such as mental imagery of grasping movements (Decety et al., 1994). Functionally defined sub-regions could be distinguished in the Broca's complex: BA47 and BA45 are involved in semantic processing; BA44, BA45, and BA46 participate in syntactic processing; and BA44 is involved in phonological processing. Hagoort (2005) proposes that "the common denominator of the Broca's complex is its role in selection and unification operations by which individual pieces of lexical information are bound together into representational structures spanning multiword utterances" (p. 166). Its core function is, consequently, *binding the elements of the language*.

Thompson-Schill (2005) analyzed the different deficits observed in cases of damage in Broca's area: articulation, syntax, selection, and verbal working memory, suggesting that there may be more than a single function. The author proposes a framework for describing the deficits observed in different patients. The proposed framework suggests that Broca's area may be involved in *selecting information among competing sources*. Fadiga, Craighero, and Roy (2006) speculate that the original role played by Broca's area relates to *generating/extracting action meanings*; that is, organizing/interpreting the sequence of individual meaningless movements. Ardila and Bernal (2007) conjectured that the central role of Broca's area was related to *sequencing motor/expressive elements*. Novick, Trueswell, and Thompson (2005) consider that the role of Broca's area is related with a general *cognitive control mechanism for the syntactic processing of sentences*.

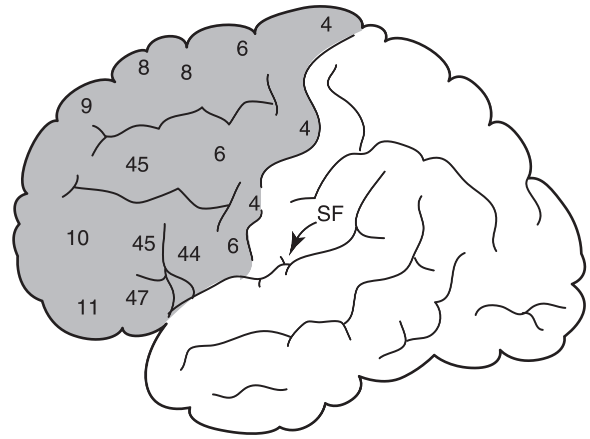

Figure 7-3 Anatomical map of Broca's complex. B45 and BA47 are involved in semantic processing; BA44, BA45 and BA46 participate in semantic processing; and BA44 and BA6 have a role in phonological processing. [Adapted from Hagoort, P. (2005). Broca's complex as the unification of space for language. In A. Cutler (Ed.), *Twenty-first century psycholinguistics: Four cornerstones* (p. 162). Mahwah, NJ: Lawrence Erlbaum Associates.]

Grodzinsky (2000, 2006) has presented an extensive analysis of the role of Broca's area. He proposed that most syntax is not located in Broca's area and its vicinity (operculum, insula, and subjacent white matter). This brain area does have a role in syntactic processing, but a highly specific one: *it is the neural home to receptive mechanisms involved in the computation of the relation between transformationally moved phrasal constituents and their extraction sites (syntactic movement)*. He further assumes that Broca's area is also involved in the construction of higher parts of the syntactic tree in speech production. Interestingly, blood flow in Broca's area increases when subjects process complex syntax (Caplan, Alpert, Waters, & Olivieri, 2000). Syntax is indeed neurologically segregated, and its components are housed in several distinct cerebral locations far beyond the traditional ones (Broca's and Wernicke's regions). A new brain map for syntax would also include portions of the right cerebral hemisphere (Grodzinsky & Friederici, 2006).

In summary, regardless of the fact that expressive language disturbances have been associated for over a century with damage in the left inferior frontal gyrus (later known as "Broca's area"), currently there is incomplete agreement about its limits and its specific functions in language. Different proposals have been presented to explain language disturbances in so-called Broca's aphasia, including: binding the elements of the language (Hagoort, 2005); selecting information among competing sources (Thompson-Schill, 2005); generating/extracting action meanings (Fadiga et al., 2006); sequencing motor/expressive elements (Ardila & Bernal, 2007); acting as a cognitive control mechanism for the syntactic processing of sentences (Novick et al., 2005); constructing higher parts of the syntactic tree in speech production (Grodzinsky, 2000, 2006); and engaging in verbal working memory (Haverkort, 2005).

However, not only does Broca's area participate in linguistic processes, it also participates in nonlinguistic processes, such as memory—particularly working memory (Rämä et al., 2001; Ranganath et al., 2003; Sun et al., 2005), solving arithmetical tasks (Rickard et al., 2000), music enjoyment (Koelsch, Fritz, Cramon, et al., 2006), and diverse motor tasks, such as observation of expressive gestures and motor acts (Lotze et al., 2006), motor imagery (Grezes & Decety, 2002), and understanding actions of other individuals (Fazio et al., 2009). Departing from these observations, the existence of a mirror-neurons system in humans related with BA44 has been suggested (Rizzolatti & Craighero, 2004).

Transcortical (Extrasylvian) Motor Aphasia as a "Dysexecutive Aphasia"

Transcortical (extrasylvian) motor aphasia corresponds to Luria dynamic aphasia (Luria, 1976). It is characterized by nonfluent verbal output, a lack of verbal initiative, good comprehension, and good repetition of spoken language. Patients with this subtype of aphasia use as few words as possible, answer questions by reiterating many of the words and grammatical structures presented in the question (echolalia), and, on occasion, produce perseverative responses. Sentences tend to be started but not finished. Poor verbal fluency, impoverished narrative production, reduced use of complex and precise syntax, and poor inhibition of high-association responses have been described following left prefrontal damage (Kertesz, 1999). These patients perform speech series well once the series has been initiated. Recitation of nursery rhymes and naming the days of the week are often performed successfully if initiated by the examiner. Open-ended phrases are easily completed by these patients. Comprehension of spoken language is good, at least for conversational language. However, many patients have difficulty handling sequences of complex material, and some show defects in interpreting relational words. Interestingly, despite preserved language understanding, patients with this type of aphasia have difficulties following verbal commands.

The difficulty of these patients in initiating a response is complicated by significant apathy and behavioral withdrawal that is usually observed. These patients seem distant and not interested in engaging in social conversation. Luria (1980) proposed that in dynamic aphasia, the patient's behavior is not controlled by language, and the dissociation between language and overt behavior represents an executive control disorder impairing language at the pragmatic level. Some authors have supposed that in dynamic aphasia a selective impairment of verbal planning occurs (Costello & Warrington, 1989), particularly at the level of "macroplanning," that is, generating sequences of novel thoughts and ideas (Bormann, Wallesch, & Blanken, 2008). Alexander suggested that this type of aphasia could be more accurately defined as an executive function disorder rather than aphasia (2006). He proposed that the progression of clinical disorders from aphasia to discourse impairments can be interpreted as a sequence of procedural impairments from basic morphosyntax to elaborated grammar to narrative language, correlated with a progression of the focus of the damage from posterior frontal to polar, or lateral frontal to medial frontal, or both.

The ability of these aphasic patients to repeat utterances is unexpectedly good in dramatic contrast to their nonfluent spontaneous output. Although the patients often echo a word or phrase, they usually are not fully echolalic. The ability to name on confrontation is often limited. Three types of errors are found in confrontation naming: (1) Perseveration: the patient continues giving a past response for a new stimulus. (2) Fragmentation: the patient responds to a single feature of the stimulus, not to the whole stimulus. (3) Extravagant paraphasias: instead of the target name, the patient presents a free-association answer that becomes an extravagant deviation (Benson & Ardila, 1996).

Writing is almost always defective. Sentences are incomplete, and the patients must be continuously encouraged to continue writing. Complex aspects of writing, such as planning, narrative coherence, and maintained attention, are significantly disturbed ("dysexecutive agraphia," according to Ardila & Surloff, 2006).

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Neurologic findings in this type of extrasylvian motor aphasia are variable. Hemiparesis is uncommon. Pathological reflexes involving the dominant limb are often present. Both conjugate deviation of the eyes and unilateral inattention have been recorded in the initial stages in some cases of dynamic aphasia. Damage is expected to involve BA45 (which is situated in front of Broca's area) and adjacent brain areas.

Extrasylvian (transcortical) motor aphasia can be interpreted as an executive function defect specifically affecting language use. The ability to actively and appropriately generate language appears impaired while the phonology, lexicon, semantics, and grammar are preserved. Extrasylvian (transcortical) motor aphasia could indeed be referred to as "dysexecutive aphasia" (Ardila, 2009).

Frontal Language Abilities and Metacognition

Disagreement persists around the potential unitary factor underlying executive functions. It can be suggested that "action representation" (i.e., internally representing movements) may constitute at least one basic metacognitive executive function factor. Several authors have argued that thought, reasoning, and other forms of complex cognition (metacognition) depend on an interiorization of actions. Vygotsky (1929, 1934/1962, 1934/1978), for instance, proposed that thought (and in general, complex cognitive processes) is associated with some inner speech. More recently, Lieberman (2002a, 2002b) suggested that language in particular and cognition in general arise from complex sequences of motor activities. Noteworthy, the frontal lobe, and particularly Broca's area, is involved in understanding actions of other individuals (Fazio et al., 2009).

Vygotsky's (1934/1962, 1934/1978) understanding of "higher mental functions" is roughly equivalent to "metacognitive executive functions." The central point in Vygotsky's (1934/1962) idea is that higher forms of cognition ("cognitive executive functions") depend on certain mediation (instruments), very specially, language. According to Vygotsky (1934/1962), the invention (or discovery) of these instruments will result in a new type of evolution (cultural evolution), not requiring any further biological changes. Thinking is interpreted as a covert motor activity ("inner speech").

Vygotsky (1929) assumes that thought and speech develop differently and independently having different genetic roots. Before 2 years of age, the development of thought and speech are separate. They converge and join at about the age of 2 years, and thought from this point ahead becomes language mediated (verbal thought). Language in consequence becomes the primary instrument for conceptualization and thinking. According to Vygotsky (1934/1962), speech develops first as external communicative/social speech, then egocentric speech, and finally inner speech.

Inner speech is for oneself while external, social speech is for others. Vygotsky considered that thought development is determined by language. School is intimately related with learning a new conceptual instrument: reading. Written language is an extension of oral language, and it represents the most elaborated form of language.

In brief, Vygotsky (1934/1962) argued that complex psychological processes (metacognitive executive functions) derive from language internalization. Thinking relies on the development of an instrument (language or any other), that represents a cultural product. Lieberman (2002a, 2002b) refers specifically to the origins of language. He postulates that neural circuits linking activity in anatomically segregated populations of neurons in subcortical structures and the neocortex throughout the human brain regulate complex behaviors such as walking, talking, and comprehending the meaning of sentences. The neural substrates that regulate motor control (the basal ganglia, cerebellum, and frontal cortex) in the common ancestor of apes and humans most likely were modified to enhance cognitive and linguistic ability. Lieberman (2002a, 2002b) suggests that motor activity is the departing point for cognition. Speech communication played a central role in this process. The neural bases of mankind's linguistic ability are complex, involving structures other than Broca's and Wernicke's areas. Many other cortical areas and subcortical structures form part of the neural circuits and are implicated in the lexicon, speech production and perception, and syntax. The subcortical basal ganglia support the cortical–striatal–cortical circuits that regulate speech production, complex syntax, and the acquisition of the motor and cognitive pattern generators that underlie speech production and syntax. They most likely are involved in learning the semantic referents and sound patterns that are instantiated as words in the brain's dictionary.

These two authors (Vygotsky and Lieberman), although using rather different approaches, have both postulated that the development of language and complex cognition are related with motor programming, sequencing, internalizing actions, and the like. Ardila (2009) argued that, historically, language developed in two different steps: initially as a lexical/semantic system, and more recently as a grammatical system. Grammar represents a sequencing of symbolic/linguistic elements (interiorization of actions), provides thinking strategies, and is related with the development of metacognitive executive functions.

The discovery of so-called "mirror neurons" represents a new element in understanding inner speech and action representation. A mirror neuron is a neuron which fires both when an animal performs an action and also when the animal observes the same action performed by another animal. In humans, brain activity consistent with mirror neurons has been found in the premotor cortex and the inferior parietal cortex (Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). These neurons (mirror neurons) appear to represent a system that matches observed events to similar, internally generated actions. As mentioned earlier, Broca's area participates in understanding actions of other individuals (Fazio et al., 2009).

Transcranial magnetic stimulation and positron emission tomography (PET) experiments suggest that a mirror system for gesture recognition also exists in humans and includes Broca's area (Rizzolatti & Arbib, 1998). The discovery of mirror neurons in Broca's area might have immense consequences for understanding the organization and evolution of mankind cognition (Arbib, 2006; Craighero, Metta, Sandini, & Fadiga, 2007). An obvious implication of mirror neurons is that they can participate in the internal representation of actions. PET studies have associated the neural correlates of inner language with activity of Broca's area (McGuire et al., 1996).

CONCLUSIONS

Despite the fact that the term "executive functions" was coined just a couple of decades ago, this concept has become a fundamental cornerstone in understanding human cognition. It has been observed that executive functions depend on extended dynamic networks including different brain areas, but the prefrontal cortex plays a major role in controlling and monitoring these areas. Noteworthy, "executive functions" is not a unitary concept, and the definition of executive functions includes two different dimensions: emotional/motivational (behavioral dimension), and metacognitive (cognitive dimension).

A diversity of communication disturbances can be observed in cases of frontal lobe pathology; some of them are more directly associated with social/emotional impairments in the use of language and are frequently found in cases of right frontal lobe pathology; others are more specifically related with the ability to use language as a cognitive instrument and are frequently observed in cases of left frontal lobe pathology. So-called transcortical (or extrasylvian) motor aphasia could be interpreted as a defect in the executive control of language ("dysexecutive aphasia").

Contemporary neuroimaging studies have significantly advanced the understanding of the role of the frontal lobe in language. It has become evident that the prefrontal cortex has a monitoring role in language. Using neuroimaging techniques, it has been observed that the performance of a diversity of verbal tasks results in changes of the activation level in different prefrontal areas.

Traditionally, language production has been related with Broca's area; Broca's area corresponds to BA44, but several contemporary authors also include BA45. Regardless of the fact that it has been assumed that damage in Broca's area was responsible for the clinical manifestations observed in Broca's aphasia, contemporary studies have demonstrated that damaged restricted to this area only results in mildly nonfluent speech, relatively short sentences and mild agrammatism; phonetic deviations and a few phonological paraphasias can also be observed. The complete and classical Broca's aphasia requires significantly more extended lesions, including the opercular region, the precentral gyrus, the anterior insula, and the paraventricular and periventricular white matter.

The specific role of Broca's area has been polemic, and different suggestions have been presented, including binding the elements of language, selecting information among competing sources, generating/extracting action meanings, sequencing motor/expressive elements, acting as a cognitive control mechanism for the syntactic processing of sentences, constructing higher parts of the syntactic tree in speech production, and engaging in verbal working memory. However, Broca's area does not only participate in linguistic processes, but also in nonlinguistic processes such as observation of expressive gestures and motor acts, motor imagery, and understanding actions of other individuals. It has been suggested that the existence of a mirror-neurons system in humans is related with BA44.

Some authors have proposed that the development of metacognitive executive functions is related with motor programming, sequencing, and internalizing actions. Further, grammar represents a sequencing of symbolic/linguistic elements and is associated with the development of metacognitive executive functions.

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