Cognitive processes and neural basis of language switching: proposal of a new model

Sylvie Moritz-Gasser[a,b,c] and Hugues Duffau[b,c]

Although studies on bilingualism are abundant, cognitive processes and neural foundations of language switching received less attention. The aim of our study is to provide new insights to this still open question: do dedicated region(s) for language switching exist or is this function underlain by a distributed circuit of interconnected brain areas, part of a more general cognitive system? On the basis of recent behavioral, neuroimaging, and brain stimulation studies, we propose an original 'hodological' model of language switching. This process might be subserved by a large-scale cortico-subcortical network, with an executive system (prefrontal cortex, anterior cingulum, caudate nucleus) controlling a more dedicated language subcircuit, which involves postero-temporal areas, supramarginal and angular gyri, Broca's area, and the superior longitudinal fasciculus. ***NeuroReport*** **00:000–000 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Departments of [a]Neurology, [b]Neurosurgery, Hôpital Gui de Chauliac and [c]Institut of Neuroscience of Montpellier, Plasticity of Central Nervous System, Human Stem Cells and Glial Tumors, Hôpital Saint Eloi, CHU Montpellier, Montpellier, France

Correspondence to Professor Hugues Duffau, MD, PhD, Department of Neurosurgery, Hôpital Gui de Chauliac, CHU de Montpellier, 80 Avenue Augustin Fliche, Montpellier 34295, France
Tel: +33 4 67 33 66 12; fax: +33 4 67 33 75 57;
e-mail: h-duffau@chu-montpellier.fr

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Introduction

In bilingual individuals, language switching means to pass from one language to another during speech, voluntarily or not. Studies about bilingual aphasic individuals have allowed differentiating pathological switching (involuntary) from pathological mixing. In the first case, individuals switch from one language to another when they pass from one utterance to another. In the second case, they mix the two languages in the same utterance [1].

Although behavioral and neurofunctional studies on bilingualism are abundant, neurocognitive processes and neural foundations of language switching have received less attention. Here, we review the results about cognitive models and neural basis of switching to provide new insights to this still open question: does dedicated region(s) for language switching exist or is this function underlain by a distributed cortico-subcortical network of interconnected brain areas, part of a more general cognitive system?

Cognitive processes

First, it is important to address the cognitive processes involved in language switching. All studies agree that when an individual recognizes a word in one or the other languages he practices, the semantic system activates both lexicons [2–4]. Words might not be organized by languages, but by frequency of use [5]. Two frameworks are conflicting regarding the choice of the target language. The first one asserts that there is a competition between the two lexicons and that the speaker can inhibit selectively the word of the nontarget lexicon [6]. On the contrary, the second one asserts that the two lexicons are not in competition to select the target word: therefore, lexical selection would be specific to the target language [2].

The first framework includes the asymmetric switching cost notion [7], which corresponds to a more important cognitive cost to pass from the second language (L2) to the first language (L1) than the opposite. It could be explained by a more important L1 saliency entailing the necessity of a stronger inhibition and consequently a more important cost to remove this inhibition when the individual wants to reactivate L1. This cost might be asymmetric when switching is imposed but symmetric when switching is voluntary. Even if language switching is originally of a significant cognitive cost for linguistic skills, highlighted by the increase of response times in switching tasks compared with tasks in only one language – whatever the L2 mastery level – [2,8], the asymmetric cost switching notion described in the first framework is not observed in early bilinguals (i.e. both languages learned before puberty) who can switch from L1 to L2 or from L2 to L1, for the same cost [2].

Christoffels *et al.* [9] suggest that 'sustained' mechanisms of language control have to be distinguished from 'transient' mechanisms of language control. However, the involvement of inhibition mechanisms is found in most of the studies [3,6,10,11] and seems to be confirmed by neuroimaging (see below). It is now commonly admitted that the language switching mechanism, as any cognitive switching (i.e., in one language, to pass from

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one semantic category to another, or to adapt to change in the rules of a cognitive skill) is part of a more general executive system [12,13].

However, there is still a debate concerning this switching mechanism. Some authors advocate that language switching is independent of language processes [13]. According to this model, when language switching is pathological, it would be elicited by pragmatic disorders of communication – at the opposite of language mixing, which is associated with anomia in bilingual aphasic individuals. When language switching is voluntary, it is made possible – thanks to a more general cognitive system. On the contrary, other authors suggest, using functional neuroimaging, that there is a participation of peculiar areas to language switching, compared with switching cognitive tasks in one language [10,14–17]. Therefore, a better knowledge of the functional anatomy subserving language switching is crucial to solve this debate and to understand cognitive processes.

Neural basis

In 1930, Poetzl [18] thought he had found the switch area in the left inferior parietal lobule, thanks to studying brain lesions of aphasic patients with pathological language switching. Current brain mapping studies show us that the complex cognitive process of language switching depends, in fact, on a lot of cerebral structures. Nonetheless, some authors support the existence of dedicated regions involved in language switching, whereas others think that this function is only a part of a more general cognitive system (Table 1).

In favor of the latter hypothesis, the involvement of left frontal/prefrontal areas is highlighted by many studies. In addition to the left dorsolateral prefrontal cortex [19,20], the anterior prefrontal area could be involved in inhibition mechanism and the left mesial prefrontal cortex and supplementary motor area (SMA) would be implied in the control of interferences with the nontarget language [21]. The more L2 master level is weak, the more left prefrontal activation might be important during switching tasks [10]. Interestingly, Fabbro *et al.* [1] described a pathological language switching without any other language disorder in a patient with a lesion involving left (and more slightly right) anterior cingulum, left premotor area, and a large part of the left frontal lobe, involving subcortical structures.

Table 1 Review of the literature about neural basis of language switching: neuroimaging and brain stimulation studies

Chee *et al.* [19]	Left prefrontal cortex
Holtzheimer *et al.* [20]	Left dorsolateral prefrontal cortex
Rodriguez-Fornells *et al.* [21]	Left mesial prefrontal cortex, SMA
Fabbro *et al.* [1]	Left anterior cingulum, left premotor area, and subcortical structures
Crinion *et al.* [15]	Left caudate head
Hernandez *et al.* [12]	SMG
Quaresima *et al.* [22]	Left IFG
Khateb *et al.* [16]	Left precentral frontal gyrus, left SMG, left AG
Abutalebi *et al.* [14]	Left prefrontal-basal ganglia loop involving prefrontal cortex, anterior cingulum, basal ganglia, IPL
Price *et al.* [17]	Left IFG, bilateral SMG, left medial fusiform gyrus
Kho *et al.* [23]	Left IFG
Moritz-Gasser *et al.* [24]	Posterior part of the superior temporal gyrus, SLF

AG, angular gyrus; IFG, inferior frontal gyrus; IPL, inferior parietal lobule; SLF, superior longitudinal fasciculus; SMA, supplementary motor area; SMG, supramarginal gyrus.

Conversely, authors advocating that there is a participation of a peculiar area in language switching based their conclusions, using functional neuroimaging, on more important activations during language switching tasks compared with cognitive switching tasks in only one language. For instance, Quaresima *et al.* [22] noted the role of the left inferior frontal gyrus (Broca's area) and Hernandez *et al.* [12] highlighted the role of the supramarginal gyrus. Interestingly, Jackson *et al.* [25] found a difference of brain activity during a productive or receptive language-switching task. Productive task entailed an increased activity in frontal and parietal areas, whereas in receptive task this activity was missing, with activations in the central region, that is, in nonspecific language areas.

Currently, more and more recent studies plead in favor of the coexistence of both the mechanisms. Indeed, Khateb *et al.* [16] proposed that language selection in bilingual individuals was possible – thanks to a neural network including brain areas involved in general cognitive processes and in language processing. They highlighted the involvement of a left cortico-cortical fronto-parietal circuit including precentral frontal gyrus, anterior supramarginal gyrus, and angular gyrus. In addition, Abutalebi *et al.* [14] suggested the existence of a left cortico-subcortical loop. They described the activations, during language switching tasks, of prefrontal cortex (interpreted as related to executive functions), anterior cingulum (related to attention and errors detection), inferior parietal lobule (related to maintenance of representations and working memory), and basal ganglia (interpreted as language planning and lexical selection), that is, the involvement of several levels of cognitive control and language production. Thus, a single network for L1 and L2 representations might exist, modulated by structures of cognitive control. Indeed, Crinion *et al.* [15] reported the role of left caudate head in control and monitoring of the target language. These data are in agreement with one of our previous studies based on intraoperative electrical mapping in awake patients who underwent surgery for a tumor involving the left striatum. We demonstrated that stimulation of the head of the dominant caudate nucleus systematically elicited perseverations, supporting the role of this structure in cognitive control [26]. Interestingly, although Price *et al.* [17] also observed the distributed cortico-subcortical activations, they noted a difference in patterns between translation and switching. To translate words from L1 to L2, they described activations within the anterior cingulate gyrus and subcortical structures (putamen, head of caudate), as well as involvement of the left anterior insula, SMA and brainstem, that is, areas involved in articulation. Conversely, switching from one language to another entailed Broca's area and supramarginalis gyri activation, in contrast areas involved in phonological processing, as well as activation of the left medial fusiform gyrus.

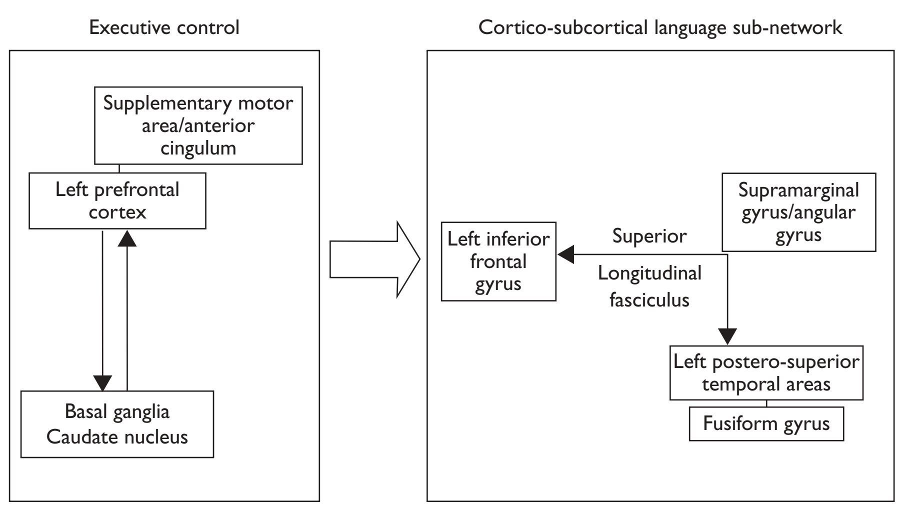
Nonetheless, although neuroimaging works provided new insights into the brain areas involved in language switching, it is important to interpret their results carefully. In reality, we have to remind that an 'activation' in a certain area reported in a functional neuroimaging study is 'greater activity' in a brain structure during the performance of a task in comparison with activity during the performance of another task. Therefore, this 'greater activity' does not mean that none of the other areas is activated: it is a relative activation, dependent on the nature of the control task. In contrast, a review of the sole functional neuroimaging literature is not reliable enough. It is the reason why it is also crucial to focus on works based on invasive techniques, particularly direct brain electrostimulation, whose results seem more instructive. Indeed, when the neurosurgeon stimulates one brain area during some seconds, the cognitive result (i.e. involuntary language switching) induced by this transient virtual lesion indicates with certainty that this brain area is essential for this cognitive process [23,24].

Yet, until now, contrary to the functional neuroimaging works, very scarce studies used invasive techniques of direct brain electrostimulation as well as Wada test to get a better understanding of the functional anatomy of language switching. Nevertheless, in two manuscripts, we revealed the existence of a large-scale distributed network underlain not only by several cortical areas but also by white matter pathways. First, Kho *et al.* [23] highlighted that intraoperative electrical stimulation of the left inferior frontal gyrus (Broca's area), as well as its inactivation by Wada test, led to an involuntary language switching. It was hypothesized that the left dominant inferior frontal gyrus was a crucial epicenter for language switching, the involuntary switching during its inhibition being explained as the result of a transient disconnection within a large-scale circuit. In addition, we recently reported a patient in whom intraoperative electrostimulation of a discrete area within the posterior part of the left dominant superior temporal gyrus elicited reproducible language switching under local anesthesia. Interestingly, involuntary switching was also generated by the stimulation of the superior longitudinal fasciculus [24]. This subcortical pathway connecting this temporal area with Broca's area, itself being the producer of involuntary language switching [23], we suggested that language switching was underlain by a large cortico-subcortical network, in a hodological rather than in a localisationist view of this kind of language processing – that is, in cortico-cortical and cortico-subcortical parallel and distributed networks [27].

Conclusion

Even if all authors agree to assert the essential role of prefrontal areas in cognitive mechanisms of language switching-role likely related to the implication of inhibitory processes and executive functions – the existence of specific language areas is still discussed. Interestingly, the more recent studies converge toward the same hypothesis, that is, several cortical and subcortical areas take part in language switching, namely the prefrontal

Fig. 1



Model of distributed neural network of language switching, which involves a subset of cortical and subcortical language areas, modulated by cortico-striatal structures implied in cognitive control.

areas, left anterior cingulate/SMA, left inferior frontal gyrus, supramarginalis gyri, left angular gyrus, and basal ganglia, especially the head of the caudate nucleus.

Moreover, studies based on intraoperative electrical stimulation introduced a connectionist view, with not only the involvement of a subset of several cortical areas, but also the implication of the superior longitudinal fasciculus in language switching, eliciting a transient disconnection between language switching epicenters during stimulation. These results are in agreement with functional MRI studies suggesting the existence of a fronto-basal loop [14], and with event-related potential works supporting the involvement of a fronto-parietal circuit [16]. The electrostimulation studies also allow, as suggested by Kroll *et al.* [3], to map the connections between language control mechanisms and cognitive skills. On the basis of this 'hodological' organization of language switching [27], we propose that this process is underlain by an executive system (prefrontal cortex, anterior cingulum, caudate) controlling a more dedicated language subcircuit, which involves posterior temporal areas, supramarginal and angular gyri, Broca's area, and superior longitudinal fasciculus (Fig. 1). Such model might enable a better understanding of the mechanisms involved in pathological or aberrant switching, and thus to elaborate specific programs of language rehabilitation, with the goal to optimize the recovery of both the languages in bilinguals, but also the possibility to switch voluntarily between them.

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