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Research report

Involvement of the middle frontal gyrus in language switching as revealed by electrical stimulation mapping and functional magnetic resonance imaging in bilingual brain tumor patients

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ABSTRACT

Neural basis of language switching and the cognitive models of bilingualism remain controversial. We explored the functional neuroanatomy of language switching implementing a new multimodal protocol assessing neuropsychological, functional magnetic resonance and intraoperative electrical stimulation mapping results.

A prospective series of 9 Spanish–Catalan bilingual candidates for awake brain surgery underwent a specific language switching paradigm implemented both before and after surgery, throughout the electrical stimulation procedure and during functional magnetic

Abbreviations: LS, Language switching; ESM, electrical stimulation mapping; IFG, inferior frontal gyrus; MFG, middle frontal gyrus; SFG, superior frontal gyrus.

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resonance both pre- and postoperatively. All patients were harboring left-hemispheric intrinsic brain lesions and were presenting functional language-related activations within the affected hemisphere.

Language functional maps were reconstructed on the basis of the intraoperative electrical stimulation results and compared to the functional magnetic resonance findings. Single language-naming sites (Spanish and Catalan), as well as language switching naming sites were detected by electrical stimulation mapping in 8 patients (in one patient only Spanish related sites were detected). Single naming points outnumbered the switching points and did not overlap with each other. Within the frontal lobe, the single language naming sites were found significantly more frequently within the inferior frontal gyrus as compared to the middle frontal gyrus [X^2 (1) = 20.3, $p < .001$]. Contrarily, switching naming sites were distributed across the middle frontal gyrus significantly more often than within the inferior frontal gyrus [X^2 (1) = 4.1, $p = .043$]. Notably, there was not always an overlap between functional magnetic resonance and electrical stimulation mapping findings. After surgery, patients did not report involuntary language switching and their neuropsychological scores did not differ significantly from the pre-surgical examinations. Our results suggest a functional division of the frontal cortex between naming and language switching functions, supporting that non-language specific cognitive control prefrontal regions (middle frontal gyrus) are essential to maintain an effective communication together with the classical language-related sites (inferior frontal gyrus).

1. Introduction

It is an intriguing topic how bilinguals are able to switch, seemingly effortlessly, between the languages they speak (Crinion et al., 2006; Rodriguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002). Language switching (LS) allows effective communication in bilingual communities by enabling individuals to appropriately select the target language as a function of external cues such as linguistic knowledge of their interlocutor, face-related cues or contextual effects (Bialystok, Craik, & Luk, 2012; Gollan & Ferreira, 2009; Rodriguez-Fornells et al., 2011; Soveri, Rodriguez-Fornells, & Laine, 2011). When bilingual language control is impaired, LS can be considered pathological (Fabbro et al., 2000). Pathological switching is defined as the phenomena of passing from one utterance/sentence to another without appropriately adapting the language in use to the given situation (Fabbro et al., 2000). As every cognitive function, LS may be impaired if the intrinsic brain organization is impacted by a brain lesion (i.e., brain tumor).

Intraoperative electrical stimulation mapping (ESM) has been the gold standard technique for identifying essential sensory and motor cortex as well as cortical language areas in patients undergoing tumor resection (Duffau, 2008; Ojemann, 1983; Penfield & Roberts, 1959). Although single-language naming tasks are the most extended tool to map language function during awake brain surgery (Corina et al., 2010; Havas et al., 2015; Lubrano, Prod'homme, Démonet, & Köpke, 2012), there is an increasing need to adapt intraoperative neuropsychological tasks to map specific brain functions such as LS in order to preserve an optimal quality of life according to the patient's specific life characteristics (Fernandez-Coello et al., 2013). However, the literature concerning the intraoperative monitoring of LS in multilingual brain tumor patients is rather scarce.

Even if the intraoperative evidences on LS are yet to be explored, evidence from other studies using functional magnetic resonance imaging (fMRI) (Abutalebi et al., 2008; Chee, Soon, & Lee, 2003; Hernandez, 2009; Hernandez, Dapretto, & Mazziotta, 2001; Hernandez, Martinez, & Kohnert, 2000; Rodriguez-Fornells et al., 2002), electroencephalography (EEG) (Khateb et al., 2007; Kuipers & Thierry, 2010; Moreno, Federmeier, & Kutas, 2002; Proverbio, Leoni, & Zani, 2004) and transcranial magnetic stimulation (TMS) (Holtzheimer, Fawaz, Wilson, & Avery, 2005; Nardone et al., 2011) support the idea that LS, similarly as task switching, is sustained (at least partially) by a more general executive control system (Fabbro, 2001; Guo, Liu, Misra, & Kroll, 2011; Hernandez et al., 2001; Hervais-Adelman, Moser-Mercer, & Golestani, 2011; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). However, there is still no agreement concerning the brain regions selectively recruited during LS. On the one hand, Fabbro (2001) stated that voluntary language switching is based on a more general control mechanism independently of language processing suggesting that pathological LS results from pragmatic disorders of communication (not benefiting from contextual/social cues that support effective communication). Following this perspective, LS would be sustained by non-domain specific cognitive control systems. In contrast, other studies directly comparing task switching to LS suggest some differences in control mechanisms across linguistic and non-linguistic domains (Calabria et al., 2016; Crinion et al., 2006; Prior and Gollan, 2011; Weissberger et al., 2012), proposing the implication of language domain specific areas in LS compared to cognitive switching occurring when speaking only one language.

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