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The role of Area 10 (BA10) in human multitasking and in social cognition: A lesion study

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ABSTRACT

A role for rostral prefrontal cortex (BA10) has been proposed in multitasking, in particular, the selection and maintenance of higher order internal goals while other sub-goals are being performed. BA10 has also been implicated in the ability to infer someone else's feelings and thoughts, often referred to as theory of mind. While most of the data to support these views come from functional neuroimaging studies, lesion studies are scant. In the present study, we compared the performance of a group of frontal patients whose lesions involved BA10, a group of frontal patients whose lesions did not affect this area (nonBA10), and a group of healthy controls on tests requiring multitasking and complex theory of mind judgments. Only the group with lesions involving BA10 showed deficits on multitasking and theory of mind tasks when compared with control subjects. NonBA10 patients performed more poorly than controls on an executive function screening tool, particularly on measures of response inhibition and abstract reasoning, suggesting that theory of mind and multitasking deficits following lesions to BA10 cannot be explained by a general worsening of executive function. In addition, we searched for correlations between performance and volume of damage within different subregions of BA10. Significant correlations were found between multitasking performance and volume of damage in right lateral BA10, and between theory of mind and total BA10 lesion volume. These findings stress the potential pivotal role of BA10 in higher order cognitive functions.

1. Introduction

The prefrontal cortex (PFC) is the cortical region in the frontal lobe anterior to the primary and association motor cortices. This brain area increases in size with phylogenetic development and, at least in humans, it is thought to be involved in planning complex cognitive behavior and in the expression of personality and appropriate social conduct. The prefrontal cortex is an anatomically and functionally heterogeneous structure and comprises cytoarchitectonically distinct regions, accounting for about 30% of our total cortical area (Fuster, 1997). Understanding the functional organization of the prefrontal cortex and the specific roles played by each of its distinct subregions (e.g. dorsolateral or rostral areas) is an essential issue in human cognitive neuroscience. Large volumes of data derived from functional neuroimaging have led to the statement of multiple influential theories regarding these issues. In order to draw stronger inferences, human lesion studies, which highlight the critical regions within brain networks, are crucial to complement functional neuroimaging approaches.

Brodmann Area 10 (BA10), also known as the frontal pole or rostral/anterior prefrontal cortex, is the largest and most anterior region within the human PFC (Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001). Having experienced remarkable evolutionary expansion, this brain region also shows higher spine density than other areas of the human cortex and is highly interconnected with supramodal areas within the PFC in which information is believed to be represented at its most abstract level (Ramnani & Owen, 2004). All of the above suggests that BA10 plays an important role in human cognition. Accordingly, several authors have placed this brain region at the top of a frontal processing hierarchy (Badre & D'Esposito, 2007; Koechlin, Ody, & Kouneiher, 2003).

One function attributed to the anterior PFC is multitasking, in particular, the selection and maintenance of higher order internal goals while other sub-goals are being performed (e.g. Badre

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Table 1
Patient characteristics.

Patient		Age	Sex	Aetiology	Side	Estimated premorbid IQ	Years POST Onset	Total lesion volume in ml	BA10 lesion volume in ml
BA10 group									
1	IB	39	F	Tumor	Bilateral	120	1	62.25	17.79
2	MS	64	F	Tumor	Right	111	5	9.50	2.66
3	DP	41	M	Tumor	Bilateral	115	1	66.83	7.21
4	SV	41	F	Tumor	Bilateral	128	2	60.02	14.95
5	SS	54	F	Tumor	Right	97	11	71.63	11.76
6	PM	54	M	Tumor	Left	121	9	31.34	9.4
7	ET	57	F	Infarct	Right	126	12	57.93	9.37
NonBA10 group									
1	PP	67	F	Tumor	Left	103	11	18.15	–
2	LB	29	F	Tumor	Right	88	8 months	78.76	–
3	AD	71	F	Infarct	Left	120	13	26.21	–
4	MS	77	M	Infarct	Right	121	11	12.95	–
5	GB	51	M	Tumor	Right	100	17	47.24	–
6	FG	47	F	Tumor	Right	106	9	87.65	–
7	RB	61	M	Tumor	Right	106	8	3.29	–
8	RH	75	F	Tumor	Right	118	27	32.57	–

& D'Esposito, 2009; Burgess, Dumonheil, & Gilbert, 2007; Gilbert, Frith, & Burgess, 2005; Gilbert et al., 2006, 2007; Koechlin & Summerfield, 2007). Maintenance and flexible retrieval of higher order goals enable us to orient our behavior to internal plans, rather than merely responding to the external environment. Most of the supporting data come from functional neuroimaging studies, and while multitasking and planning deficits have been described in patients with extensive frontal cortex damage (e.g. Goldstein, Bernard, Fenwick, Burgess, & McNeil, 1993; Hebb & Penfield, 1940; Shallice & Burgess, 1991), there are only a few lesion studies that have systematically assessed the specific role of BA10 in this domain. In a pioneering study, Burgess, Veitch, de Lacy Costello, and Shallice (2000) showed that damage to the more medial and polar aspects of BA8, 9 and 10, in the left hemisphere, was associated with more internal task switching deficits than right dorsolateral prefrontal lesions. However, the specific role of BA10 was not assessed, and the deficits found could also be related to simple rule breaking behavior, which was indeed part of the overall score reported. Recently, Dreher, Koechlin, Tierney, and Grafman (2008) also showed that in a group of patients with frontal lesions, deficits in multitasking correlated with the extent of damage in BA10. However, patients with closed head injuries were included in their study, making it hard to distinguish the effects of focal lesions and more diffuse damage. Two more recent lesion studies (Umeda, Kurosaki, Terasawa, Kato, & Miyahara, 2011; Volle, Gonen-Yaacovi, de Lacy Costello, Gilbert, & Burgess, 2011) have related rostral prefrontal cortex to prospective memory (the capacity to carry out intended actions after a delayed period of time), perhaps a critical element of multitasking.

Besides the maintenance and retrieval of higher order goals, functional neuroimaging has also linked BA10 to the ability to infer someone else's feelings and thoughts, demanding a complex set of functions collectively referred to as theory of mind. In fact, several functional neuroimaging studies have shown rostral PFC activation when the ability to infer other people's thoughts and emotions was assessed (e.g. Gilbert et al., 2006, 2007; Sommer et al., 2007). Again, while some lesion studies have shown that frontal damage can impair performance on theory of mind tasks (Narvid et al., 2009; Rowe, Bullock, Polkey, & Morris, 2001; Shamay-Tsoory, Tibi-Elhanany, & Aharon-Peretz, 2006; Shamay-Tsoory & Aharon-Peretz, 2007; Stone, Baron-Cohen, & Knight, 1998; Stuss, Gallup, & Alexander, 2001), no studies have yet investigated the role of BA10 in particular.

Based on neuroimaging findings, functional specialization within BA10 has been proposed both in the lateral-medial and anterior–posterior axes (Gilbert et al., 2007). Medial BA10, especially its posterior part, is supposed to play a major role in mentalizing and theory of mind (Gilbert et al., 2006, 2007). On the other hand, lateral BA10 seems necessary in human multitasking when attending to the outside world is not enough, and an internal goal is needed to direct behavior; that is, when cognition must be directed by stimulus-independent thought (Burgess et al., 2007; Dumontheil, Gilbert, Frith, & Burgess, 2010; Gilbert et al., 2005; Koechlin & Summerfield, 2007).

In the present study, we examined the role of BA10 both in multitasking and in theory of mind by comparing a group of frontal patients whose lesions affected BA10, a group of frontal patients whose lesions did not affect that area and a group of normal controls. We hypothesized that, if BA10 indeed plays a role in these cognitive functions, patients with lesions affecting this area would have impaired performance on tasks of multitasking and theory of mind relative to controls and patients with nonBA10 lesions. Moreover, given the findings from neuroimaging studies suggesting functional specialization across different BA10 subregions, we examined correlations between behavioral deficits and volume of damage within specific BA10 regions.

2. Material and methods

2.1. Subjects

Fifteen patients with chronic focal frontal lesions were recruited from the Cambridge Cognitive Neuroscience Research Panel at the MRC Cognition and Brain Sciences Unit in Cambridge, UK ($n = 11$) and from the INECO Research Data Base in Buenos Aires, Argentina ($n = 4$). All patients had a single focal lesion, verified by MRI, confined to frontal structures. Lesion aetiology was mostly tumor resection or cerebrovascular disease (Table 1). Exclusion criteria were current/previous psychiatric diagnosis, color blindness, additional neurological disease and history of diffuse brain damage. All patients gave informed consent prior to inclusion. Patients were selected from a larger cohort described in greater detail elsewhere (Roca et al., 2010) and were divided into groups on the basis of whether ("BA10" group) or not ("nonBA10" group) their lesions involved BA10 (*see below*).

Twenty-five healthy control volunteers were recruited from the volunteer panel of the MRC Cognition and Brain Sciences Unit ($n = 7$) and through advertisement in Buenos Aires ($n = 18$) and were matched with patients for age and estimated premorbid IQ. Premorbid intelligence was estimated using the revised National Adult Reading Test (NART; Nelson & Willison, 1991) for British subjects and the WAT-BA (Burin, Jorge, Arizaga, & Paulsen, 2000; Del Ser, González-Montalvo, Martínez-Espinosa, Delgado-Villapalos, & Bermejo, 1997) for Argentineans. Since patients were predominantly recruited from the UK, but controls from Argentina, British and Argentinean control subjects were compared on all measures in the study. No significant differences were found.

2.2. Neuroradiological assessment

MRI scans were performed for all patients and interpreted by a neurologist with experience in structural neuroimaging, who was blind to the experimental results