

Effortless control: executive attention and conscious feeling of mental effort are dissociable

Lionel Naccache^{a,b,d,*}, Stanislas Dehaene^b, Laurent Cohen^{b,d}, Marie-Odile Habert^c,
Elodie Guichart-Gomez^d, Damien Galanaud^e, Jean-Claude Willer^a

^a *Clinical Neurophysiology Department, Hôpital de la Salpêtrière, 47 Boulevard de l'Hopital, IFR 49, 75013 Paris, France*

^b *Institut National de la Santé et de la Recherche Médicale, Unité INSERM 562, IFR 49, CEA/DRM/DSV, Orsay, France*

^c *Nuclear Medicine Department, Hôpital de la Salpêtrière, 47 Boulevard de l'Hopital, IFR 49, 75013 Paris, France*

^d *Neurology Department, Hôpital de la Salpêtrière, 47 Boulevard de l'Hopital, IFR 49, 75013 Paris, France*

^e *Neuroradiology Department, Hôpital de la Salpêtrière, 47 Boulevard de l'Hopital, IFR 49, 75013 Paris, France*

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Abstract

Recruitment of executive attention is normally associated to a subjective feeling of mental effort. Here we investigate the nature of this coupling in a patient with a left mesio-frontal cortex lesion including the anterior cingulate cortex (ACC), and in a group of comparison subjects using a Stroop paradigm. We show that in normal subjects, subjective increases in effort associated with executive control correlate with higher skin-conductance responses (SCRs). However, our patient experienced no conscious feeling of mental effort and showed no SCR, in spite of exhibiting normal executive control, and residual right anterior cingulate activity measured with event-related potentials (ERPs). Finally, this patient demonstrated a pattern of impaired behavior and SCRs in the Iowa gambling task—elaborated by Damasio, Bechara and colleagues—replicating the findings reported by these authors for other patients with mesio-frontal lesions. Taken together, these results call for a theoretical refinement by revealing a decoupling between conscious cognitive control and consciously reportable feelings. Moreover, they reveal a fundamental distinction, observed here within the same patient, between the cognitive operations which are depending on normal somatic marker processing, and those which are withstanding to impairments of this system.

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“But I see well what still misleads you, it is that to stir up your arm, it is not sufficient that you want it, rather it is necessary for you to make some effort. And you think that this effort, of which you have interior feeling, is the true cause of the movement which follows it. But my son, do you clearly see some relationship between what you call effort, and the determination of the animal spirits in the pipes of the nerves which are used for the movements that you want to produce?” Nicolas Malebranche, *Méditations Chrétiennes* (1683).

1. Introduction

The involvement of the prefrontal cortex in the ability to engage executive control constitutes one of the fundamental results of cognitive neuroscience. Current research focuses on the respective roles of frontal lobe structures such as anterior cingulate cortex (ACC), dorso-lateral prefrontal cortex (DLPFC), or orbito-frontal cortex (OFC) in this general process of control. Most investigated aspects of control include conflict detection and estimation, executive control modulation and response selection processes. In particular, diverging theories stimulate experimental research on the precise role of ACC in control. One influential theory postulates that ACC is involved in conflict monitoring and serves as a regulator signaling to other executive regions such as DLPFC whether

* Corresponding author. Tel.: +33 1 40 77 97 99; fax: +33 1 40 77 97 89.
E-mail address: lionel.naccache@wanadoo.fr (L. Naccache).

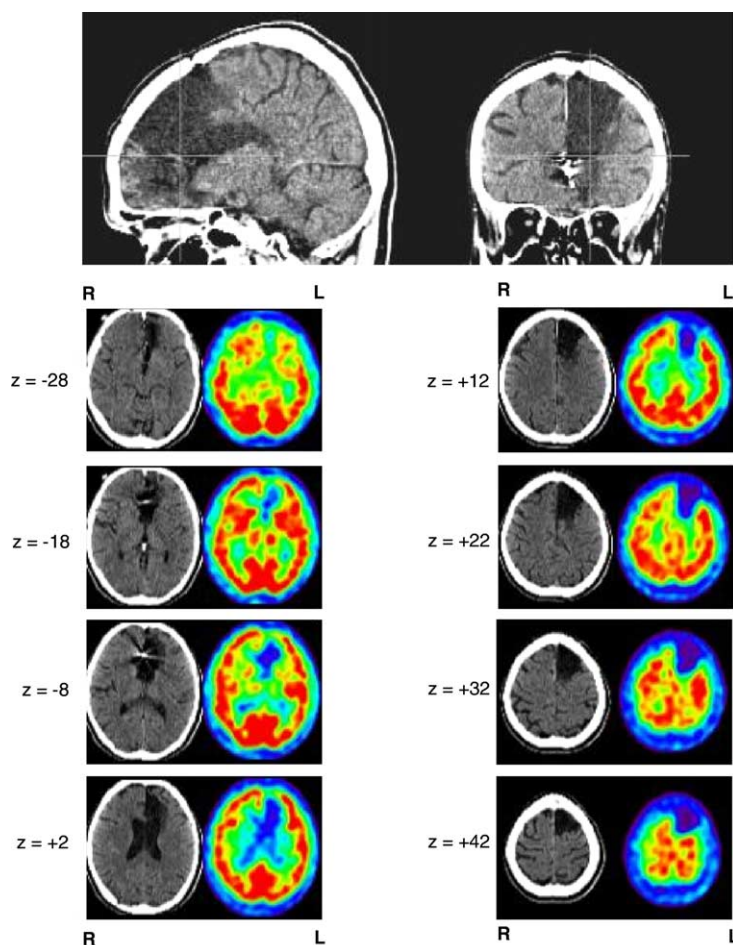


Fig. 1. Anatomy of patient RMB's lesion. Sagittal and coronal sections of a high resolution brain CT-scan ($0.39 \text{ mm} \times 0.39 \text{ mm} \times 1 \text{ mm}$), and eight axial sections of CT-scan and rest SPECT normalized in Talairach's space using SPM2 (z coordinate is provided for each pair of sections) reveal a stroke lesion delineating part of the left anterior cerebral artery territory. Only the rolandic part of this arterial territory is spared, in accordance with the clinical examination confirming the absence of right motor limb deficit.

executive attention has to be reinforced or alleviated (Botvinick, Braver et al., 2001). Another theory attributes to ACC a more active function related to response selection, as illustrated by patients exhibiting dissociations between control abilities depending on the motor response modality (Turken & Swick, 1999).

Within this scientific context, we planned to explore control abilities in patient RMB, a 50-year-old woman presenting with a vast left mesio-frontal ischaemic lesion including the left ACC (Fig. 1). We were initially motivated by the perspective of describing control impairments likely to be found in such a patient, and then to test which theory would best account for them.

We designed a set of behavioral experiments using a simplified Stroop task in which, on each trial the subject had to respond according to the ink color of a color word (e.g. the word "red" written in green ink) (Carter, Macdonald et al., 2000). Stroop trials can be sorted into two categories: congruent trials in which both the ink color and the word itself refer to the same response, and incongruent trials in which the subject has to focus his executive attention to select the

relevant information (the ink color) and to inhibit the prepotent response associated with the irrelevant information (the printed color word). Incongruent trials are usually responded slower and with a greater subjective feeling of mental effort.

Our results section begins with a detailed description of patient RMB's performance in this Stroop task (Experiments 1–3). Unexpectedly, control abilities of patient RMB evaluated in various versions of this Stroop tasks were amazingly preserved, and no dissociation was observed between manual and vocal response modalities. Moreover, we could show the presence of an efficient dynamic regulation of control abilities as indexed by Gratton and proportion effects.

However, we accidentally discovered that she had lost entirely the ability to experience and report a feeling of mental effort normally present during this task. In order to better assess and describe this unexpected deficit, we designed a further set of experiments exploring subjective verbal and non-verbal report of mental effort during the Stroop task in patient RMB and in normals (Experiments 4–7).

Once we could establish the existence of a dissociation between preserved cognitive aspects of control on the one hand,

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