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# Speed-accuracy strategy regulations in prefrontal tumor patients

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ABSTRACT

The ability to flexibly switch between fast and accurate decisions is crucial in everyday life. Recent neuroimaging evidence suggested that left lateral prefrontal cortex plays a role in switching from a quick response strategy to an accurate one. However, the causal role of the left prefrontal cortex in this particular, non-verbal, strategy switch has never been demonstrated. To fill this gap, we administered a perceptual decision-making task to neuro-oncological prefrontal patients, in which the requirement to be quick or accurate changed randomly on a trial-by-trial basis. To directly assess hemispheric asymmetries in speed-accuracy regulation, patients were tested a few days before and a few days after surgical excision of a brain tumor involving either the left ($N=13$) or the right ($N=12$) lateral frontal brain region. A group of age- and education-matched healthy controls was also recruited. To gain more insight on the component processes implied in the task, performance data (accuracy and speed) were not only analyzed separately but also submitted to a diffusion model analysis. The main findings indicated that the left prefrontal patients were impaired in appropriately adopting stricter response criteria in speed-to-accuracy switching trials with respect to healthy controls and right prefrontal patients, who were not impaired in this condition. This study demonstrates that the prefrontal cortex in the left hemisphere is necessary for flexible behavioral regulations, in particular when setting stricter response criteria is required in order to successfully switch from a speedy strategy to an accurate one.



## 1. Introduction

We are often required to flexibly switch between rapid and accurate decision-making. When we adopt a rapid response strategy, we inevitably sacrifice accuracy, whereas a harsh response criterion will typically slow down performance. The cognitive nature of this so-called speed/accuracy trade-off has been heavily investigated for more than a century (e.g., Woodworth, 1899; Fitts, 1966; Zelaznik et al., 1988). Experimentally, it is well established that we are able to flexibly trade speed for accuracy and vice versa, depending on instructions (Hick, 1952; Howell and Kreidler, 1963), payoffs (Swensson, 1972) and deadlines (Garrett, 1922; Pachella et al., 1968).

Given the ongoing interest in speed/accuracy strategies from the cognitive viewpoint, it is surprising that the neural mechanisms underlying these strategies, and particularly the capacity to dynamically switch between them, are still poorly understood. Two previous functional magnetic resonance imaging (fMRI) studies (Ivanoff et al., 2008; Van Veen et al., 2008) found that the middle frontal gyrus (i.e., dorsolateral prefrontal cortex) is involved in adjusting baseline activity in decision-related cortical regions to prioritize speed or accuracy. In both studies, however, speed-accuracy instructions were manipulated block-wise, making it impossible to unveil switch-related mechanisms. Another study (Forstmann et al., 2008) instead adopted an event-related fMRI design, and showed that speed instructions activated the pre-supplementary motor area and the striatum, two regions associated with the adjustment of response threshold. The authors, however, did not focus on conditions with a switch between response strategies.

A more recent fMRI study pointed at fronto-parietal regions for speed/accuracy tradeoff regulations (Vallesi et al., 2012). This study adopted a diffusion model approach (e.g., Ratcliff, 1978; Voss and Voss, 2007), which allows combining both response times and accuracy data in the same analytical steps, in order to estimate parameters linked to both decisional and non-decisional processes. The results of this fMRI study showed that the level of activation in the left middle frontal gyrus, during a cue phase

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preceding the target-related implementation of a perceptual decision-making task, was positively correlated with the adoption of a stricter response criterion, as estimated with diffusion models (Voss and Voss, 2007), when switching from a hasty response strategy to an accurate one.

While a previous study already showed that lesions to ventromedial frontal cortex impair the accuracy of value-based decision-making and not response speed (Henri-Bhargava et al., 2012), to the best of our knowledge, no other neuropsychological study has more specifically investigated how damage to frontal lobes may impair the capacity to switch from a quick to an accurate decision. Given the above reviewed neuroimaging evidence (Vallesi et al., 2012), a candidate region for this capacity within the frontal lobes is the left lateral prefrontal cortex. Left prefrontal patients suffer from cognitive flexibility problems, including the failure to set a criterion for a response, especially when other non-relevant but prepotent responses need to be suppressed (Vallesi, 2012). Examples of tasks in which this left-lateralized frontal deficit has been found include color-word Stroop interference (Perret, 1974; Stuss et al., 2001), verbal fluency by first letter (Baldo et al., 2006; Stuss et al., 1998), random number generation (Knoch et al., 2005; Jahanshahi et al., 1998), and task-switching (Stablum et al., 1994; Rogers et al., 1998; Mecklinger et al., 1999; Shallice et al., 2008). Most of these tests strongly tax verbal processing, and the left lateralization of the criterion-setting function could be a side effect of these demands (e.g., Mecklinger et al., 1999). For this reason, it would be particularly important to test whether criterion-setting critically requires the left prefrontal cortex even in a task with minimal verbal requirements.

In this neuropsychological study, we tested whether the left prefrontal cortex is not only associated to the flexible regulation of speed-accuracy strategy switching in decision-making (Vallesi et al., 2012), but also *necessary* for this high-level executive process. A further goal was to demonstrate the specificity, within the prefrontal cortex, of left hemispheric lesions to cause a deficit in this type of cognitive ability as compared to right homologous ones, even in a test with low verbal demands. To test these hypotheses, we administered a perceptual decision-making task that required continuous speed-accuracy regulation (modified from Vallesi et al., 2012) to patients with unilateral tumors located in either the left or the right lateral frontal cortex. We tested patients both a few days before and a few days after the surgical removal of the brain tumor. We expected left prefrontal patients, but not right ones or a group of well-matched healthy controls, to be selectively impaired in switching from speed to accuracy. Capitalizing on the benefits derived from the use of drift diffusion models in understanding behavioral effects, primarily the fact that they provide a more integrated and insightful picture of the processes involved in a task than speed or accuracy measures separately, which are also starting to emerge in patient studies (e.g., Moustafa et al., 2015; Vallesi et al., 2015), we analyzed our data using this approach. In particular, based on previous fMRI evidence (Vallesi et al., 2012), we expected that the most sensitive performance index for a left-prefrontal impairment in speed-to-accuracy response strategy shift would be a diffusion model parameter marking the conservativeness of the adopted response strategy.

## 2. Material and methods

### 2.1. Participants

Twenty-five patients with brain tumors, who were hospitalized at the Santa Maria della Misericordia Hospital, Udine, were included in this study. Inclusion criteria were: age between 18 and 75 years and the presence of a single brain tumor involving either the left or the right lateral prefrontal cortex (i.e., BA 9, 10, 11, 44, 45, 46 or 47) but could also extend to temporal or parietal regions. The sample of patients mainly suffered from High Grade Gliomas ($n=12$), Low Grade Gliomas ($n=8$), but also Meningiomas ($n=4$) and Metastases ($n=1$). Apart from the 25 included patients, other patients were excluded a posteriori. These comprised: patients with multiple separate lesions ($n=1$); patients who did not complete both experimental sessions ($n=5$) or who were not able to understand the instructions ($n=2$); patients with lesions involving frontal lobes only in their motor/premotor components (i.e., BA 4, 6 and/or 8; $n=8$, 4 in the left hemisphere and 4 in the right one). Due to time constraints, the latter information became available only after an accurate tumor reconstruction, which was usually performed after data collection. Thirteen of the included patients had a lesion involving left prefrontal areas, while twelve other patients had tumors located in the right prefrontal areas. The mean age was 45.92 years (sd=14.25) and the mean education was 13.44 years (sd=3.23). No differences in either age (*t*-test's $p=0.786$) or education ($p=0.638$) were found between the two groups of patients. Female/Male ratio was 5/8 for the left frontal group and 4/8 for the right frontal group. A summary of all the demographic and etiological characteristics of the participants is detailed in Table 1. Apart from one ambidextrous left frontal patient, all the other patients were right handed, as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971).

Patients were tested with a computerized speed-accuracy task (described below) in two separate sessions: a few days (range: 1–5 days) before the operation and a few days (range: 4–21 days) after the surgery. The lag between the two sessions was 9.09 days on average (sd=3.41) and no significant differences were reported in the lag across the two patient groups ($p=0.401$). In both occasions patients were also administered a comprehensive neuropsychological assessment covering the main cognitive domains: language, attention, executive function, memory and perception, together with the computerized experimental task.

A control group of 37 healthy volunteers was also recruited (mean age=45.1 years, sd=14.8, range: 23–67 years; mean education=13.7 years, sd=3.7, range=8–21 years; females/males=15/22). All of them were right handed as assessed with the Edinburgh Handedness Inventory. Each control participant was

**Table 1**
Demographic and etiological characteristics of the three samples of participants.

| | Etiology[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *N* | Low-Grade Glioma | High-Grade Glioma | Metastasis | Meningioma | F/M | Age (range) | Education years (range) | Mean lesion volume: cc (sd) | Handedness |
| Left prefrontal | 13 | 4 | 8 | 0 | 1 | 5/8 | 45.1 (19–69) | 13.8 (8–17) | 118.1 (78.6) | 12 right-handed, 1 ambidextrous |
| Right prefrontal | 12 | 4 | 4 | 1 | 3 | 4/8 | 46.7 (32–64) | 13 (8–17) | 123.7 (58.9) | All right-handed |
| Healthy controls | 37 | – | – | – | – | 15/22 | 45.1 (23–67) | 13.7 (8–21) | – | All right-handed |

[a] Definitive etiological data were provided about two weeks after surgical operation, when the results of the histopathological examination became available.