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WHITE MATTER AND TASK-SWITCHING IN YOUNG ADULTS: A DIFFUSION TENSOR IMAGING STUDY

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Abstract—The capacity to flexibly switch between different task rules has been previously associated with distributed fronto-parietal networks, predominantly in the left hemisphere for phasic switching sub-processes, and in the right hemisphere for more tonic aspects of task-switching, such as rule maintenance and management. It is thus likely that the white matter (WM) connectivity between these regions is critical in sustaining the flexibility required by task-switching. This study examined the relationship between WM microstructure in young adults and task-switching performance in different paradigms: classical shape-color, spatial and grammatical tasks. The main results showed an association between WM integrity in anterior portions of the corpus callosum (genu and body) and a sustained measure of task-switching performance. In particular, a higher fractional anisotropy and a lower radial diffusivity in these WM regions were associated with smaller mixing costs both in the spatial task-switching paradigm and in the shape-color one, as confirmed by a conjunction analysis. No association was found with behavioral measures obtained in the grammatical task-switching paradigm. The switch costs, a measure of phasic switching processes, were not correlated with WM microstructure in any task. This study shows that a more efficient inter-hemispheric connectivity within the frontal lobes favors sustained task-switching processes, especially with task contexts embedding non-verbal components. © 2016 The Author(s). Published by Elsevier Ltd on behalf of IBRO. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Key words: task-switching, fractional anisotropy, radial diffusivity, executive functions, corpus callosum, FSL.

INTRODUCTION

The capacity to switch from one rule to another in order to accomplish internal or external goals is an important executive function at the basis of cognitive flexibility. This capacity has been experimentally investigated through the task-switching paradigm (e.g., Rogers and Monsell, 1995). Performance on this paradigm involves two partially dissociable control processes: transient (or local) control and sustained (or global) control (Braver et al., 2003). These processes are captured by two different behavioral effects: (a) switch costs, that is, performance difference between trials in which the rule changes and trials in which it is repeated in mixed task blocks; and (b) mixing costs, that is, performance difference between repetition conditions during mixed-task blocks and single task conditions in pure blocks, respectively.

Neuroimaging studies have characterized distributed networks of fronto-parietal and striatal regions during task-switching (Dove et al., 2000; Brass and von Cramon, 2004; Badre and Wagner, 2006; Jamadar et al., 2015). The key domain- and rule-independent task-switching-related cognitive control processes have been mainly located in fronto-parietal networks of the left hemisphere (Kim et al., 2011; Jamadar et al., 2015; Vallesi et al., 2015; cf. De Baene et al., 2012, for an alternative view based on adaptation mechanisms).

However, additional right lateral prefrontal recruitment has been observed for task-switching paradigms with non-verbal (i.e., spatial) rules (e.g., Vallesi et al., 2015), compatibly with what happens in other high-level cognitive domains such as inductive reasoning (e.g., Babcock and Vallesi, 2015). Moreover, previous neuroimaging evidence (Braver et al., 2003) showed that right anterior prefrontal regions were activated in mixed (vs. single-task) blocks, which require the capacity to maintain and manage task-rules over-time (also see Ambrosini and Vallesi, 2016 for converging resting-state electroencephalographic evidence).

Thus, given the distributed nature of the brain circuits involved in task switching (Dove et al., 2000; Kim et al., 2012; Jamadar et al., 2015), white matter (WM) connectivity studies with Diffusion Tensor Imaging (DTI) are especially important to fully characterize the neural underpinning of these functions.

DTI provides an *in vivo* estimate of WM microstructure by measuring the degree and orientation of preferential diffusion of water molecules in neural tissue (Basser and Pierpaoli, 1996; Beaulieu, 2002; Le Bihan, 2003).

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Abbreviations: DTI, Diffusion Tensor Imaging; EPI, echo-planar image; FA, fractional anisotropy; fMRI, functional magnetic resonance imaging; MNI, Montreal Neurological Institute; RD, radial diffusivity; ROIs, Regions Of Interest; RTs, response times; SD, standard deviation; WM, white matter.

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Several scalar indices are extracted from this model to summarize this information at the voxel level (Alexander et al., 2007). Fractional anisotropy (FA) is the most commonly used value, that describes the fraction of the tensor related to anisotropic water diffusion, while radial diffusivity (RD) describes the degree of water dispersion in the plane perpendicular to the main diffusivity direction. Higher FA and lower RD values are related to increased WM integrity and fiber organization (Pfefferbaum et al., 2000; O'Sullivan et al., 2001).

A previous multimodal neuroimaging study (Gold et al., 2010) using a number-letter task-switching paradigm already tested the relationship between WM integrity in twelve pre-selected Regions Of Interest (ROIs) and global switching costs (i.e., RT difference between mixed vs. single task conditions) in twenty younger and twenty older adults. In general, global mixing costs were negatively correlated with FA bilaterally in the superior longitudinal fasciculus and pericallosal frontal regions, suggesting that the integrity of WM tracts connecting prefrontal regions or fronto-parietal regions is associated with better task-switching (i.e., lower global switching costs). However, when considering the younger participants alone, only the WM-behavior correlation with the left superior longitudinal fasciculus survived.

Another recent DTI study on 10–16-year-old adolescents (Seghete et al., 2013) found a positive correlation between FA in superior corona radiata and precentral gyrus and global task-switching performance, regardless of age, whereas an association between FA in the anterior corona radiata and task-switching was present only in interaction with age.

An important aim of the present study was to investigate whether the integrity of some WM tracts is associated to task-switching performance based on, or independently of, the specific nature of the task-switching rules employed. Therefore, as a novel contribution to the still scant literature on the association between DTI and task-switching performance in young adults (see Gold et al., 2010; Seghete et al., 2013; Treit et al., 2014, for developmentally oriented studies), rather than focusing on a single task-switching paradigm, we operationalized the task-switching construct with three different paradigms performed by the same individuals, with different degrees of verbal and non-verbal demands, and correlated the performance measures of task-switching efficiency on all these paradigms with WM integrity measures, both separately and by means of conjunction analyses across the paradigms which showed significant associations. The goal of a cross-paradigm replication is not only motivated by the theoretical question regarding the existence of common brain mechanisms underlying cognitive flexibility, but should also be seen as a methodological attempt to better characterize structural brain-behavior correlations, a field in which it is hard to replicate results even within the same experimental paradigms (Boekel et al., 2015).

Preliminary analyses of our data did not show any reliable relationship between WM integrity and phasic task-switching costs (RT difference between switch and repeat trials). This might be due to the fact that similar neural and cognitive mechanisms might be implicated in both switch ad repeat trials, although at a different level, especially with equal probability of occurrence of the two trial types (Braver et al., 2003; Crone et al., 2006; Ruge et al., 2013). Similar null results between switch cost measures and DTI have been reported in a study with children aged 7–16 years (Treit et al., 2014). Therefore, we will report our results on mixing costs, classically calculated as the performance difference between repeat trials and single-task trials, excluding switch trials (cf., Gold et al., 2010; Seghete et al., 2013). Mixing costs are believed to indicate the active and sustained maintenance and coordination of multiple task rules, functions that have been dissociated from the phasic processing differences involved in switch vs. repeat conditions behaviorally (Rubin and Meiran, 2005), neurophysiologically (Wylie et al., 2009; Ambrosini and Vallesi, 2016) and with functional magnetic resonance imaging (fMRI) (Braver et al., 2003; Wang et al., 2009). Finally, we adopted a whole-brain approach to characterize the role of all main WM fibers, while avoiding any a priori choice of ROIs that could possibly bias the results by leaving some of the main tracts unexplored.

Our main original expectations included a role of (i) the (left) superior longitudinal fasciculus in general task-switching performance, as previously reported in the DTI study by Gold and colleagues (2010), and as expected from the general involvement of left fronto-parietal regions in fMRI studies on task-switching (e.g., Kim et al., 2011; Vallesi et al., 2015), and (ii) peri-callosal cross-hemispheric anterior fiber tracts connecting homologous prefrontal regions in supporting better task-switching performance, in terms of mixing costs (Braver et al., 2003), especially when obtained in tasks with embedded non-verbal components (Vallesi et al., 2015).

EXPERIMENTAL PROCEDURES

Participants

Thirty-eight university students voluntarily took part in the experiment. We used a sample size that was nearly double with respect to that of healthy young adults tested in previous DTI work on task switching (Gold et al., 2010), as an attempt to increase statistical power, especially considering that this population shows low inter-subject variability in WM structure.

All participants gave their written informed consent prior to recruitment. They were reimbursed 25 euros for their time. All had normal or corrected-to-normal visual acuity, reported having normal color vision and no history of any neurologic/psychiatric disease. The study was approved by the Bioethical Committee of the Azienda Ospedaliera di Padova. Three participants were excluded from the analyses because of incomplete data or poor data quality. The final number of included participants was 35. All of them were right-handed (which was an inclusion criterion), as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). The average score at this test was 84.1, with a range of 45–100, over a possible total range between −100 and