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Development of abstract thinking during childhood and adolescence: The role of rostrolateral prefrontal cortex

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ABSTRACT

Rostral prefrontal cortex (RPFC) has increased in size and changed in terms of its cellular organisation during primate evolution. In parallel emerged the ability to detach oneself from the immediate environment to process abstract thoughts and solve problems and to understand other individuals' thoughts and intentions. Rostrolateral prefrontal cortex (RLPFC) is thought to play an important role in supporting the integration of abstract, often self-generated, thoughts. Thoughts can be temporally abstract and relate to long term goals, or past or future events, or relationally abstract and focus on the relationships between representations rather than simple stimulus features. Behavioural studies have provided evidence of a prolonged development of the cognitive functions associated with RLPFC, in particular logical and relational reasoning, but also episodic memory retrieval and prospective memory. Functional and structural neuroimaging studies provide further support for a prolonged development of RLPFC during adolescence, with some evidence of increased specialisation of RLPFC activation for relational integration and aspects of episodic memory retrieval. Topics for future research will be discussed, such as the role of medial RPFC in processing abstract thoughts in the social domain, the possibility of training abstract thinking in the domain of reasoning, and links to education.

Contents

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1. Introduction

Abstract thoughts can be broadly defined as thoughts that are self-generated and stimuli-independent, in contrast to stimulus-oriented, perceptually-derived, information. Beyond this definition, two particular forms of abstraction can be considered (see Nee et al., 2014). Abstraction can be defined temporally: abstract thoughts are those that relate to long term goals, or past or future events. Alternately, abstraction can be defined relationally: abstract thoughts are those that focus on the relationships between representations rather simple stimulus features. A subset of cognitive processes has particularly high requirements of abstract thoughts manipulation, either within a single temporal or relational domain, or across both. These include the retrieval of past thoughts and memories (e.g. episodic or source memory retrieval), the manipulation of current task-related or task-unrelated self-generated information (e.g. relational reasoning and problem solving or mindwandering respectively) and the processing of thoughts linked to the future (e.g. planning, multitasking, prospective memory). Interestingly, the most anterior part of the lateral prefrontal cortex, the rostrolateral prefrontal cortex (RLPFC), has been found to show increased activations in paradigms testing this whole range of cognitive functions (e.g. see Badre, 2008; Burgess et al., 2007a; Ramnani and Owen, 2004 for review). The rostral prefrontal cortex (RPFC), as other parts of the frontal cortex and the temporal cortices, shows prolonged structural development during adolescence (e.g. see Dumontheil et al., 2008 for review). The relationship between abstract thoughts and RPFC, in particular the RLPFC, during late childhood and adolescence will be the topic of this review.

Adolescence starts at the onset of puberty and can be broadly defined as between the ages of 10 and 19 (Sawyer et al., 2012). Although brain and behavioural changes during this period are less pronounced than during infancy and childhood, adolescence is nevertheless an important period of development in terms of the acquisition of higher cognitive skills, as well as the onset of mental disorders (see Dumontheil et al. (2008) for a discussion of RPFC and developmental disorders). Adolescence emerges as a critical phase of reorganisation of regulatory systems, and may also be a period of extended brain plasticity and thus a relevant target for interventions (Steinberg, 2005).

The first section of this paper will focus on the association between lateral RPFC and the ability to attend to and manipulate abstract thoughts. I will then discuss the development of this ability during late childhood and adolescence and how structural and functional development of RPFC may underlie the behavioural changes observed during adolescence. I will then briefly relate these findings to studies of the development of medial RPFC function in social cognition tasks. Finally, I will discuss future avenues of research in this field as well as potential implications of these findings for education policy and practice. This review will focus on aspects of both relationally and temporally abstract thoughts (Nee et al., 2014), as identified from the research on RLPFC function in adults. Although an effort was made to gather relevant evidence, this review is unlikely to be exhaustive and is biased towards those fields where more developmental neuroimaging research has currently been published.

Recently Ferrer et al. (2009) summarised the development of fluid reasoning, which can be considered as a type of abstract thinking. Here the goal is to perform a more extensive review of the development of abstract thinking more generally, including recent studies on the topic. Although some aspects of metacognition are relevant to the domain of abstract thought and reasoning, there has been until now little cognitive neuroscience research done with a developmental focus (see Fleming and Dolan, 2012; Fleming et al., 2010) and thus metacognition will not be reviewed here (see Schneider, 2008 for a review of the development of meta-cognitive knowledge).

2. Rostral prefrontal cortex function

2.1. Rostral prefrontal cortex: cytoarchitecture and subdivisions

RPFC, which corresponds approximately to Brodmann area 10 (BA10), is a large brain region in humans and is thought to be subdivided into separate subregions distinct