Neuropsychologia 48 (2010) 1767–1774

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

# Dopaminergic functioning and preschoolers' theory of mind

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ARTICLE INFO

*Article history:*
Received 15 April 2009
Received in revised form 23 February 2010
Accepted 25 February 2010
Available online 4 March 2010

*Keywords:*
Theory of mind
Executive functioning
Dopamine
Developmental neuropsychology
Social neuroscience

ABSTRACT

Representational theory of mind (RTM) development follows a universal developmental timetable whereby major advances in reasoning about mental representations occur between the ages of 3 and 5 years old. This progression appears to be only absent in the case of specific neurodevelopmental impairments, such as autism. Taken together, this suggests that neuromaturational factors may play a role in RTM development. Recent EEG work has shown that one neuromaturational factor pacing this universal developmental timetable is the functional maturation of medial prefrontal cortex. The neurotransmitter dopamine (DA) is thought to play a crucial role in typical frontal lobe development. Therefore, the goal of the present study was to investigate the role that DA may play in RTM development. Ninety-one 48–62-month olds were given a battery of RTM tasks along with EEG measurement. EEG recordings were analyzed for eyeblinks, a reliable indicator of DA functioning, and we calculated their average eyeblinks per minute (EBR). Regression analyses showed that EBR was associated with RTM after controlling for children's performance on a Stroop-like measure, language ability, gender, and age. These findings provide evidence that DA functioning is associated with RTM in the preschool years, and are discussed with respect to how DA might provide a mechanism that helps to account for both neurobiological and experiential factors that are known to affect the timetable of preschoolers' RTM development.


Theory of mind is the understanding that human action is motivated by internal mental states such as beliefs, desires, and intentions. In the preschool period, children's understanding of others' minds appears to change rapidly. Specifically, children come to explicitly understand that others' mental states, in particular their knowledge and beliefs, are person-specific representations of the world (Wellman, Cross, & Watson, 2001). This new understanding is sometimes called a "representational theory of mind" (RTM), and is indexed by a canonical battery of tasks, including the false-belief task. Although recent research suggests that the origins of this understanding may be present early in infancy (Onishi & Baillargeon, 2005), children's ability to recruit these concepts to explain behavior in everyday settings seems to follow a more protracted trajectory. What is perhaps most interesting is that the rapid changes in preschoolers' RTM development have been observed across cultures with vastly different world views and across multiple variants of the same basic experimental paradigm (Wellman et al., 2001). One exception to this stereotyped developmental time course includes the neurodevelopmental disorder of autism, in which theory-of-mind reasoning is specifically impaired (Baron-Cohen, Leslie, & Frith, 1985).

These findings taken together suggest that the timetable of RTM development may be constrained, at least in part, by neurodevelopmental factors, including perhaps neurochemical ones. The goal of this research is to test this hypothesis by examining the extent to which individual differences in dopaminergic functioning are associated with young children's theory of mind.

Dopamine (DA) is of primary interest in the present context for several reasons. First, recent electroencephalographic (EEG) research has shown that the functional development of the dorsal medial prefrontal cortex (dMPFC) is a specific neurodevelopmental correlate of preschoolers' RTM development (Sabbagh, Bowman, Evraire, & Ito, 2009). The dMPFC is rich in DA receptors and lies at the end of the mesocortical dopamine pathway. DA affects cell proliferation in regions that receive DA projections, including the frontal cortex (e.g., Popolo, McCarthy, & Bhide, 2004). Given that cell proliferation is a critical neurodevelopmental process, these findings provide some reason to suspect that DA might play a critical role in the healthy development and functioning of the dMPFC. Thus, we might expect DA to be associated with RTM development in preschoolers.

A second and perhaps more intriguing reason to suspect a role for DA comes from a consideration of the role that DA plays

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doi:10.1016/j.neuropsychologia.2010.02.027

in learning. A large body of literature has shown that dopaminergic activity is elicited when animals encounter situations in which their expectations about an event (such as a reward) do not match with what ultimately occurs (Schultz, 2000). It is generally thought that in these cases, dopaminergic activity promotes plasticity necessary for adjusting expectations, and coming to increasingly refined understandings of the causal structure of a given event (Schultz, 2007). This is so intriguing in the present context because one of the most robust findings from the theory of mind literature with young children is that experience plays a critical role in shaping the timetable of theory of mind development in the preschool years. One of the dominant explanations for this role of experience posits that conceptual changes take place as children gradually fine tune their understanding of how mental states affect behavior (e.g., the "theory theory," Gopnik & Wellman, 1994). These parallels between the processes associated with DA functioning and theory change provide a strong basis for hypothesizing that individual differences in DA functioning may be associated with RTM development in preschool-aged children.

To date there have been no direct investigations of the role that DA might play in RTM reasoning either in children or in adults. However, some intriguing indirect support for a relation between DA and RTM comes from research into clinical disorders associated with dopamine dysfunction. For example, recent evidence suggests that individuals with late stage Parkinson's disease, a disorder which also involves impaired DA functioning, show deficits in RTM (Péron et al., 2009). Further evidence comes from Savina and Beninger (2007), who investigated RTM performance in schizophrenic patients treated with antipsychotic mediation. Atypical antipsychotics (e.g., clozapine, olanzapine) preferentially increase dopaminergic functioning in the medial prefrontal cortex, whereas typical antipsychotics (e.g., haloperidol) do not; risperidone, although classified as an atypical antipsychotic, has an action more like that of typical antipsychotics (Heidbreder et al., 2001). Patients who were taking clozapine or olanzapine had better RTM performance than patients taking typical antipsychotics or risperidone, though the two groups showed no differences on similarly structured control tasks. These findings strongly suggest that DA projections to MPFC may be particularly critical for RTM performance.

The influence of DA on RTM development might be either direct or indirect. For instance, as the literature reviewed above suggests, DA may be important to the development and healthy functioning of relatively circumscribed regions of dMPFC that are associated with young children's RTM reasoning. In contrast, DA might play an indirect role by affecting the development and functioning of the cognitive support systems that are known to affect RTM development. One cognitive support system that is of special interest in this regard is children's executive functioning (EF) skills. Children's performance on one class of EF tasks, sometimes called response-conflict executive functioning (RC-EF) tasks, is highly correlated with performance on RTM tasks (Carlson & Moses, 2001). Furthermore, there is some evidence that aspects of executive functioning are associated with DA. Infants, toddlers and preschool-aged children who have low DA because of a dietary treatment for phenylketonuria (PKU) show specific impairment on EF tasks in comparison to control groups (Diamond, 2001 for a review). Also, in typically developing children allelic variants of DA-related genes (e.g., DRD4, COMT) are associated with RC-EF task performance such that those with a genetic predisposition to more available DA perform better on the tasks (Diamond, Briand, Fossella, & Gehlbach, 2004). Thus, we included a battery of RC-EF tasks in our study to help establish whether DA is directly or indirectly associated with RTM development.

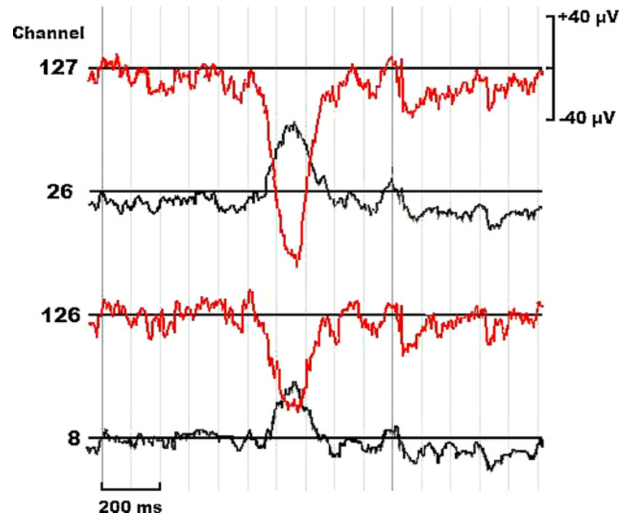


**Fig. 1.** Characteristic waveform pattern shown during an eyeblink in left channel pairs 127, 26 and right channel pairs 126, 8.

There are several well-established batteries of tasks for measuring individual differences in young children's RTM and RC-EF performance. However, measures of individual differences in DA functioning are less prominent. For the present study, we used children's eyeblink rates (EBR) as an unobtrusive way of measuring functional DA activity. EBR is governed by activity in the ventromedial caudate nucleus, part of the striatum (Taylor et al., 1999). The caudate nucleus, like the dMPFC, receives DA projections from the ventral tegmental area (VTA), though the projections to the caudate come along the mesolimbic rather than the mesocortical pathway. Most important, a number of studies using both human and other animal models have shown that experimental manipulations designed to affect levels of DA also positively affect EBR–namely, as available DA increases (for example, through the introduction of DA agonists), EBR also increases (Blin, Masson, Azulay, Fondarai, & Serratrice, 1990; Elsworth et al., 1991; Kleven & Koek, 1996). Moreover, researchers have used the EBR technique to characterize individual differences in DA functioning in developmental disorders in which dopaminergic functioning is impaired, including Attention Deficit Hyperactivity Disorder (ADHD; Konrad, Gauggel, & Schurek, 2003), and childhood onset schizophrenia (Caplan & Guthrie, 1994). Thus, EBR is a reliable indirect online measure of DA functioning in children.

The present study set out to investigate the relation between DA and RTM using a sample of archival data collected in our lab from mid-2006 to early 2007. The archival sample consisted of 60 typically developing 4-year olds for whom we had behavioral measures of their RC-EF and RTM skills, as well as resting (i.e., baseline, task-independent) EEG data. The resting EEG data was collected in a manner quite similar to the manner in which other researchers have collected EBR data (e.g., Dreisbach et al., 2005; Müller et al., 2007). Included in the recording montage were leads below and above both eyes (i.e., infraorbital and supraorbital, respectively). These pairs show characteristic sharp high amplitude waves of opposite polarity when a subject blinks (see Fig. 1), thereby allowing us to identify the number of blinks across the resting EEG recording session. We hypothesized that individual differences in EBR would be positively correlated with preschoolers' RTM performance, thereby providing indirect evidence that DA functioning of typically developing children may play some role in RTM development. Of particular interest was whether this relation was direct, or mediated by a common relation with RC-EF.