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Neural Correlates of Theory of Mind Development in Young Children

Mini Review

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Abstract

The development of the ability to attribute mental states to oneself and others (Theory of Mind, ToM) in young children is a major research focus in Cognitive Science as well as in Neuroscience. There is evidence from a limited number of studies for similarities of adults and ToM-competent children with respect to the activation of the "mentalizing" network in the brain, but very little research has addressed the processes underlying ToM development before the age of 5 years on the neural level. This review aims to synthesize the currently available neurocognitive evidence on ToM development in young children.

Abbreviations: ToM: Theory of Mind; MPFC: Medial Prefrontal Cortex; TPJ: Temporoparietal Junction; PC: Precuneus; ERPs: Event-Related Potentials; LSW: Late Slow Wave; LPC: Late Positive Complex; FNIRs : Functional Near-Infrared Spectroscopy; SMG: Supramarginal Gyrus

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Theory of Mind (ToM) refers to the fundamental human ability to understand that the behavior of others is driven by internal mental states, such as beliefs and desires. Understanding that beliefs may differ from reality and that agents act according to their beliefs, even when these are false, is at the core of ToM and develops around the age of 4 to 5 years. Recent behavioral research has found evidence for implicit false belief understanding in infancy, and explicit false belief competence in toddlers under reduced processing demands [1].

To date, relatively insufficient neuroimaging studies have been conducted on the development of ToM in children, and most of these studies have focused on older children aged 6–12 years, when ToM ability has already become well-established. The maturation of several brain regions, including the medial prefrontal cortex (MPFC), temporoparietal junction (TPJ), and precuneus (PC) has been associated with the emergence of mental state representations [2-8]. In addition to brain region activation studies, the use of event-related potentials (ERPs) in children's ToM research provides insights into the temporal neural mechanisms involved in ToM reasoning, which confirms the importance of the late slow wave (LSW) and late positive complex (LPC) in ToM development [9-12].

A seminal ERP-study by Liu, et al. [13] found that the emergence of neural activity was associated with behavioral competence in false belief reasoning in 4- to 6-year-old children. A frontal LSW characterized adults and children who understood false belief, but not children who failed a false belief task. This points to the activity of the prefrontal cortex (see also [14]). Further, Sabbagh, et al. [15] used EEG source analysis to find individual differences in resting-state alpha oscillation related to ToM performance in the right TPJ and the dorsal MPFC in 4-year-olds, indicating that the maturation of these regions is involved in the emergence of ToM. In an innovative MRI study, Grosse Wiesmann, et al. [16] related the behavioral development of false belief understanding to the maturation of white matter structure in 3- to 4-year-old children. Consistent with the neural ToM network in adults and older children, false belief understanding was associated with age-related changes in local white matter structure in the TPJ, PC and MPFC, and with increased dorsal white matter connectivity between temporoparietal and inferior frontal regions. Further, Grosse Wiesmann, et al. [17] showed that verbal ToM reasoning in 3- to 4-year-old children was supported by cortical surface area and thickness of the PC and TPJ, areas classically involved in ToM in adults. Moreover, a longitudinal study found that source-localized resting EEG in preschoolers at the age of 4 years, which is attributed to the dorsal MPFC, predicted ToM-specific fMRI responses in the dorsal MPFC at 7-8 years [18]. This suggests individual stability of early maturation processes of the dorsal MPFC which are linked to later ToM reasoning.

Despite a burgeoning behavioral literature on ToM in infancy and toddlerhood and its developmental relation to later verbal ToM [1,19], very little research has been conducted on the emergence of a specialized brain organization for ToM in infants below the age of 3 years. A study by Hyde, et al. [20] used functional near-infrared spectroscopy (fNIRs) in 7-month-old infants watching video scenes showing a person searching for a hidden object, when this person had a true belief or a false belief about the location of this object. Findings showed higher activity in the TPJ in false belief than in true belief scenarios suggesting some functional organization for higher level social cognition in infants' brains. Findings by Grosse Wiesmann, et al. [17] suggest, however, that younger children's success on implicit ToM tasks may be supported by an earlier developing, independent neural network including the supramarginal gyrus (SMG) and PC regions. This neural dissociation supports the idea that there may be two separate systems supporting implicit and explicit ToM.

In sum, the research on the development of theory of mind (ToM) in young children in the field of cognitive neuroscience is still quite limited. Nonetheless, we can have a preliminary understanding of the neural characteristics of ToM development in young children. It is important to extend this research to infancy and toddlerhood in order to trace the early emergence of a mindreading system. There is some evidence for continuity in behavioral false belief competence from toddlerhood under reduced processing demands [21], but no such evidence has been obtained on the neural level yet. Second, the relationship between implicit and explicit mindreading systems is hotly debated on the behavioral level, but to date, only one study [17] has addressed the issue of distinct neural bases of explicit and implicit ToM. Neurocognitive research with young children poses great methodological challenges. The studies reviewed above have contributed in major ways to providing ingenious new methodological approaches to the field.

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