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How Does the Brain Support Theory of Mind in Children? An EEG/ERP Review

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Abstract In the present review, the nature of children's ability to understand others' mental states is described. Incremental developments in the theory of mind (ToM) during childhood are elaborated by reviewing electroencephalography (EEG) and event-related potential (ERP) components, latency, topography, and polarity. To date, there has been no comprehensive review study on temporal mechanisms underpinning ToM among 2-11-year-old children. Therefore, to address the gap, the development of ToM is delineated from early to late childhood. Based on the experiments, 4-5-year-old children are in the early developing stage of implicit false-belief understanding. During the preschool years, children's first-order ToM develops and helps them to reflect on others' mental states. By 7 years of age, children can think/feel about what other is thinking/feeling. By 8-11 years of age, children understand the third-order ToM. In general, developmental changes germane to mental growth are found to serve the development of ToM. Temporal alterations in children's ToM, as well as their mental and meta-representational functions, are described.

Keywords: *Theory of mind (ToM), Electroencephalography (EEG), Event-related potential (ERP), Childhood, Cognition*

1. Introduction

Theory of mind (ToM) is a cognitive ability integral to human social interactions (Vishwanath et al., 2023). ToM ability represents understanding and attributing mental states to others (Quesque & Rossetti, 2020; Selcuk et al., 2023), and it is the prerequisite of effective, pragmatic language skill and social interaction (Brodsky et al., 2023; Cassidy et al., 2020; Westby & Robinson, 2014). The development of ToM foregrounds the understanding that others have goals in their minds enabling them to act and interact efficiently in situations (Hauf, 2007) and to present their social-communicative abilities (Kulke & Hinrichs, 2021; Warreyn et al., 2013). The mechanism of successful social interaction can be elucidated by reasoning about the whyness in addition to the howness of others' behaviors (Koster-Hale et al., 2017). Mental states (i.e., beliefs, values, desires, intentions, expectations, etc.) are robustly required to predict, explain, and evaluate behaviors (Kim et al., 2021). In fact, the cornerstone of the ToM

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analysis is the perspective-shifting ability (Tian et al., 2021). The concept specifically refers to the ability to differentiate between 'self' and 'other', and it incorporates cognitive mechanisms involved in the recognition and attribution of mental states, even if other's perspectives conflict with the self-perspective (Bradford et al., 2019). In this vein, the social neuroscience perspective reveals a shift away from ToM as a unitary construct to a multidimensional construct (Westby & Robinson, 2014). In principle, the new construct encompasses cognitive and affective dimensions (Tesar et al., 2020) as well as interpersonal and intrapersonal aspects (Lucariello et al., 2007). Westby and Robinson (2014) also address the multidimensionality of ToM in several stages of development and present that neonates begin to develop the basis of ToM as they initiate to imitate and reproduce movements. Dynamic interactions with the caregiver aligned with 'shared intentionality' sustain the development of ToM. Moreover, joint attention exhibits a foundational pattern in the development of ToM (Sodian et al., 2020). Cortical arousals indicate that this mentalizing capacity changes at a rapid rate during early childhood years and continues to grow in mid and late childhood (Osterhaus & Koerber, 2023; Tian et al., 2021). Thus, ToM is a developmental rather than a sudden phenomenon.

It is worth noting that ToM is a complex ability for children since it is related to their social abilities and skills (Sundqvist & Rönnberg, 2010). Studies have presented that 3-4-year-old children can differentiate mental states from biological processes and achieve a premier perception of beliefs and intentions before they acquire a deep understanding of the states (Flavell, 1999; Schult & Wellman, 1997). Afterward, the development of ToM provides the second-order false belief (FB) understanding among 6-7-year old children (Baron-Cohen, 1989). The order involves analyzing what an individual thinks/feels about what others may think/feel (Westby & Robinson, 2014). In FB reasoning, the development of abilities to judge realities and beliefs, in addition to the demonstration of how children's brain development is in line with the growth of social cognition, is important (Cassidy et al., 2020). In this view, understanding beliefs, realities, intentions, desires, and emotions is construed as the hallmark of everyday social cognition (Mukerji et al., 2019). Actually, when a person understands and predicts false behavior on the grounds of the other's FB, the phenomenon evidences that the person understands the condition not based on the world reality but based on the other's 'representation of the world' (Liu et al., 2004). Subsequently, considering a more advanced order of the FB mental state (i.e., the third-order of FB understanding) among 7-11-year-old children, researchers have found modulations in the cortical networks that underlie the understanding of white lie, misunderstanding, irony, metaphor, faux pas, figures of speech, double bluff, persuasion, etc. (Baron-Cohen et al., 1999; Jakubowska & Białecka-Pikul, 2020). Children successfully master recursive thinking, which involves the recognition of various types of information between a hearer and a speaker. During the middle to late childhood, neurophysiological changes become more advanced, helping children to control more complex conditions (Wellman et al., 2001; Wellman & Liu, 2004). Then, 9-11-year-old children mature progressively to understand faux pas, which is a combination of the 'cognitive component' and 'empathic affective component' (Stone et al., 1998). It is the ability through which children recognize a statement that may unintentionally hurt a person.

In general, ToM analysis is not easy because it deals with internal and mental states, and it is not directly observable. Hence, scholars should make inferences to predict behaviors (Premack & Woodruff, 1978). In this regard, pieces of evidence from cortical responses allow researchers to probe and track maturational changes in ToM. Oscillating electrical voltages compromise time-locked events of neural pathways, and they can be recorded via electroencephalography (EEG) and event-related potential (ERP) tools. Wiring patterns among neurons are detectable via the tools, and they manifest temporal maps across the brain areas in connection with inhibitory and excitatory neuronal interactions.

In this review study, some developmental changes in ToM appertaining to brain electrical activities across early, middle, and late childhood are depicted. Reviewing the oscillating electrical voltages in ToM, several EEG- and ERP-based studies in 2-11-year-old children were collected. The present review is not the first to point to matters of substance on ToM, but it is perhaps the most comprehensive attempt to put all the relevant EEG/ERP components together. The strategy for this review was searching English abstracts across several electronic databases (without any time limit): Google Scholar, Scopus, ProQuest, and Science Direct. Inclusion criteria of "theory of mind" were used in combination with “mental states”, “mind”, “intention”, and “belief”. The searched terms had been delineated with EEG and ERP published experiments investigated children aged between 2-11 years old.

2. 2-6-Year-Old Early Childhood

Some studies have indicated that neural oscillations unravel different stages of brain processes. For instance, alpha wave presents maturation of dorsal medial prefrontal cortex (dMPFC) and right temporal-parietal juncture (rTPJ) regions lending support to the development of the explicit representational theory of mind (RTM) in 4-year-old children (Sabbagh et al., 2009). Given that, several cues have been taken from RTM and executive function (EF) batteries as keys to evaluate the explicit ToM. The remarkable result emerging from source density is the predominant contribution of the rTPJ to RTM and domain-general tasks (Sabbagh et al., 2009), reasoning tasks (Saxe, 2006), and visual attention shift tasks (Mitchell, 2008). Moreover, considering the potent role of the dMPFC among preschoolers (Sabbagh et al., 2009), this region is also crucial for school-aged children and adults (Cassidy et al., 2020; Sabbagh et al., 2009). Importantly, the dMPFC is correlated with the RTM, but not with the EF. Likewise, dMPFC is observed in complicated ‘metarepresentational’ and ‘emotional reasoning’ (Amodio & Frith, 2006), self and other relations (Saxe, 2006), and FB tasks (Sabbagh et al., 2009). Interest in investigating the way the brain processes FB and EF and subsets of ToM have led to the conduction of some experiments on children.

Experiments on the nature of the FB ability have corroborated representational as well as non-representational ToM delving into individual’s experiences (Drover, 2014). Given the pieces of evidence provided by the ERP literature in general and the P3b component in particular, new ways have been opened to trace the FB-related changes. In this regard, notices have been given to the FB nature among 6-year-old (Meinhardt et al., 2011) and also 3.5-4.5-year old children (Drover, 2014) in response to unexpectedness. Strikingly, the P3b criterion was commonly reported around 300-500 ms (Polich, 2007), but Drover found the time window protracted to ~400-530 ms (on channels 84, 89, and 90) among the preschoolers. Furthermore, the detection of action violations provoked higher P3b amplitudes. Thereby, it is justifiable to deduce that; the P3b presents ‘conceptual updating’ and ‘conceptual understanding’ in response to unexpected conditions and incongruent beliefs. However, as children become older (~6 years), their responses become more like those of adults (Meinhardt et al., 2011). Accordingly, changes in P3b amplitudes during 4-6 years of age indicate changes in ToM. In this regard, Drover mentioned Vygotsky’s (1978) theory and implicated that those children who perform accurately in FB tasks are within their zone of proximal development.

Following the ideas about P3b as a remarkable component, some views explicate that the early performances of young children result from their simple ToM (Siegal & Varley, 2002) or implicit and non-representational understandings, progressively forming a representational understanding of FB reasoning (Drover, 2014). Indeed, young children “rely on the representational understanding of beliefs” but they are “unable to translate competence into correct performance” (Drover, 2014, p. 4). The statement affords some implications on the association between ToM reasoning and language in a way that language scaffolds propositional reasoning about ToM (Shahaeian et al., 2023; Siegal & Varley, 2002). In this regard, there is a particular functional tie between syntax and FB ability (Guan et al., 2020; Milligan et al., 2007; Slade & Ruffman, 2005). A possible reason is that mirror neurons underlying language processing in Broca’s area are also elicited in ‘witnessing goal-directed behavior’ and are connected to ToM processing (Siegal & Varley, 2002).

Lending support to the importance of FB understanding, Liu et al. (2009) conducted an experiment on children’s (4-6-year-old children) mental state development and hypothesized that the children’s behavioral performances (correct or incorrect on FB questions) mirrored conceptual changes. To meet the target, they designed several story scenarios in pictorial presentation format in which the reality and belief judgments were time-locked, and the children were asked to reason about the characters’ beliefs in the multi-trial ToM task. The children who passed the task indicated late slow-wave (LSW) in differentiating realities from beliefs (Liu et al., 2009); however, what differentiated age groups was the latency of occurrences by virtue of information processing speed (Kail, 1991). Liu and colleagues added, “the left-frontal negative LSW was found to be associated with belief-reasoning partly reflecting conceptual operations in verbal working memory recruited to solve mentalizing problems," and in terms of differentiating realities from beliefs, they noted that the "reality questions simply initiate spatial working memory and do not require any mentalizing; belief questions initiate spatial working memory but more focally require social-cognitive inferential processing in verbal working memory as well" (p. 324). The researchers also juxtaposed adults' and children's topographical distributions and noted the activation of the left-, mid-, and right-frontal electrodes among the children while they observed the left-frontal activation for adults (at ~800 ms). Notwithstanding the variations, the authors implied that the occurrence of neural specializations from childhood to adulthood leads to unique (vs. diffuse) brain regions. Moreover, the involvement of the frontal cortex in ToM and FB reasoning tasks (Liu et al., 2009; Stone et al., 1998; Stuss et al., 2001) across the ages present continued maturation in understanding the states (Liu et al., 2009).

As another paramount example of ToM understanding, EF ability comes into play. In a study on neural markers of EF in 35-54-month-old children, an ERP analysis was conducted based on the participants' performance (correct or incorrect) in the dimensional change card sort test (Zelazo, 2006), in which children were required to sort pictures based on shapes and colors as the pre- and post-switch dimensions respectively (Espinet et al., 2012). Changes in N2 amplitude were statistically significant between the children who passed and failed the test in Brodmann's areas of 129, 6, and 16. Besides, the N2 latency was manifested by 438.29 ms post-stimulus across the four brain regions. The N2 amplitude was less negative among the children who passed (vs. failed) the test. Thus, N2 can be a marker of conflict processing. This finding supports other ERP analyses (e.g., Lamm et al., 2006; Waxer & Morton, 2011) and characterizes the importance of conflict detection and the illumination of behavioral flexibility in boosting EF ability.

Recently, some of the ToM-based studies have focused on the mirror neuron system reinforcing that the implicit understanding of action largely influences ToM development (Mikhailova et al., 2021). Basically, it is believed that the mirror neurons are action-coding neurons (Lepage & Théoret, 2006; Mikhailova et al., 2021), informing a tie between action-observation and action-execution mechanisms (Rizzolatti & Craighero, 2004). EEG data have established that the mu frequency provides valuable information about the observation-execution matching systems (Lepage & Théoret, 2006). In this regard, a comparison of the variances in EEG power between observing a real versus fake action situation demonstrates a power desynchronization in the mu range (Mikhailova et al., 2021). Accordingly, observing a real action situation processing, children (17-41-month-old children) presented greater desynchronization in the mu range in the Fz and Pz regions. Moreover, observing real action situations, those with high (vs. intermediate) levels of speech assimilation processes revealed greater power desynchronization in the mu range in the F3 and P3 regions. As a result, it can be concluded that the mirror neurons and speech comprehension processes are interactive in nature.

3. 7-11-Year-Old Middle and Late Childhood

During middle and late childhood, the bilateral TPJ may support ToM and contribute to thinking about others' thoughts (vs. physical state) (Gweon et al., 2012) and social cognitive behavior (vs. non-mentalistic false content) (Mukerji et al., 2019). Besides, more electrical activations have also been found in dMPFC and rTPJ during FB reasoning (vs. true belief (TB) reasoning) (Sommer et al., 2010). In this regard, Bowman and colleagues (2019) continued Sabbagh et al.'s (2009) longitudinal experiment and repeated it among those children to analyze alterations in neuronal activation after ~3.5 years. Accordingly, the electrical activities in dMPFC aligned with alpha power promise to provide information about the children's performances. Importantly, the authors introduced dMPFC as a ToM-selective region across ages. In another experiment, Meinhardt et al. (2011) compared the age-related cortical TB and FB reasoning differences among ~7-year-old children and adults. The prospect of being able to solve the Sally-Anne Scenario (Baron-Cohen et al., 1985) has been reported to serve as a stimulus for deciding about the children's TB and FB reasoning abilities. Remarkably, the differences in the brainwaves between the TB and FB reasoning were notably made by LPC at parietal electrodes and LSW at anterior sites. The LPC time window was between 300-600 ms for both age groups; however, the LSW duration was longer for preschoolers than adults. In this manner, the mean amplitude values for LSW ranged between 600-900 and 750-1450 ms for adults and children, respectively. The

LPC and LSW waveforms in response to the FB tasks were remarkably more positive than the TB tasks. Furthermore, the age-related changes in the LPC topographies highlighted the activation of the central electrodes for the adults but the posterior and inferior regions for the children. Hence, the children's waveforms were widely distributed over the scalp, while the activations were restricted among the adults. In addition to the belief variable, the expectancy factor continued to elicit the LPC with more positive waveforms at the midline electrode site in response to unexpected (vs. expected) stories. Moreover, the LSW topography presented the involvement of the frontal site in children and also the involvement of the superior, inferior, and midline areas in adults.

Pretend play (PT) is another ToM-related issue (Kühn-Popp et al., 2013; Lillard et al., 2011; Wolf, 2022). In this regard, Kühn-Popp et al. (2013) established a three-fold condition (i.e., a non-mental control (RE), PT, and FB conditions) among children (M_{age} = 7.34 years). The authors mentioned that the common point between the PT and FB condition is distinguishing real from non-real content, and they sought to address whether PT is metarepresentational or not. While hearing a story, the participants also saw some content-related cartoon pictures. Each story consisted of a protagonist who held a piece of food in his/her hand and saw an animal in the cage (RE condition), out of the cage (PT condition), or he/she did not see the animal leaving the cage (FB condition). Behavioral data presented no meaningful differences among the RE, FB, and PT conditions, and the accuracy means were M = 81.43; M = 79.76; and M = 76.31 in each case, respectively. The registered responses were P2, then the posterior slow waves, and finally, the anterior slow waves. More specifically, an increase in the amplitude (290-420 ms) at the posterior parts was observed in response to the PT condition when the participants observed that the animal jumped out of the cage and the protagonist's action of putting food in the cage was an incompatible behavior. Functionally, P2 indicated a pattern of detecting an incongruity between the protagonist's mental state and action. Also, in the frontal electrode, the time window ranged between 290-600 ms, and it was specifically correlated with distinguishing 'mental from non-mental content' or 'simple from metarepresentational content'. However, it lasted longer (290-920 ms) in response to the FB condition at fronto-central sites. In addition, the early slow-wave activity in the frontal site highlighted the largest negativity produced in the PT (vs. FB and RE) condition. On the other hand, the LSW at the posterior region in FB condition underlined the process that "children had to shift their attention from the external information (agent puts food into the cage) toward knowledge about the agent's inner representation (animal is inside the cage)" (Kühn-Popp et al., 2013, p. 496). Hence, to understand the FB condition, children should process and reorient their attention with respect to various representations and detect the protagonists' misrepresentation of the RE condition. The upshot of the finding is that the continuous development of the cortical network progressively enables children to successfully master mental content. Given the potent role of FB understanding in ToM, in fact, it is believed that language and complementation syntax facilitates the process (Guan et al., 2020). Specifically, Guan et al. investigated the task type (belief vs. complementation) and falsehood type (false vs. true) among school-aged children. Regarding the task type, a low beta (12-16 Hz) value was found at the parieto-occipital region in response to the belief task than the complementation task. The LSW (600-900 ms) was also observed at the interaction point between the belief and the complementation variables. Pertaining to the falsehood task, the authors reported that the FB condition yielded the lowest response accuracy score. This implies that FB can be 'the most challenging condition' for children and the complementation factor is a precondition for FB comprehension.

Moreover, interest in the way the brain processes desires prior to beliefs has led to the conduction of a series of experiments to find neural changes. Following the well-established paradigm of Liu et al.'s (2009) study, Bowman and colleagues (2012) established a three-fold schema of ToM principles, including diverse-desires (for food/toys), diverse-beliefs (for food/toys), and diverse-physical locations (to put away food/toys). Preliminary analysis showed that 7-8-year-old children had better performance in solving diverse-desires (84.6%) and diverse-physical (88.3%) tasks in comparison with a diverse-belief task (65.0%). Mean amplitudes were displayed across 200-250 ms, 350-600 ms, 600-800 ms, and 800-850 ms time windows correspondingly at the right mid-frontal site; however, they were diminished after 850 ms. The grand average waveform for the belief (vs. desire) condition led to a greater mean amplitude. Notably, the difference was substantial from ~350 to ~800 ms, and there were significant differences in the correct trials from 600 to 800 ms and also from 850 to 1400 ms. Bowman et al. (2012) observed that children and adults showed similar topography (mid-frontal region) to diverse-physical locations, though with greater right hemispheric activation in children. Upon further scrutiny of the grand average ERP waveforms in adults and children, Bowman et al. reported LSW (800-850 ms) and P2 responses for adults, while P2 responses for children. They attributed the differences in the neural time course to the 'mental-state decoding'. On this account, children as early as 7 years old can distinguish between mental and physical properties.

The last important issue in describing ToM characteristics is related to mirror neurons in general and mu rhythm desynchronization in particular (Bowman et al., 2017; Hunnius & Bekkering, 2014; Saby et al., 2012). The core assumption of the mirror neurons has been mostly investigated via an observation-execution matching system between executing and pretending to execute functions. During a passive observation of actions, 11-year-old children presented a mu rhythm attenuation (Lepage & Théoret, 2006). In particular, Lepage and Théoret concluded that some movements (i.e., the rest in goal-directed movements, flat hand-observation, grip-observation, and grip execution conditions) caused greater modulation in mu rhythm in comparison with less goal-directed movements. The results confirmed traces of action-coding cells, even in immature brains. In general, changes in the EEG/ERP patterns reflect the progression of cortical areas and mental states during the developmental cognitive neuroscience process (Meinhardt et al., 2011).

4. Concluding Remarks

To substantiate changes in brainwave activities, herein, pieces of evidence on ERP and EEG signatures of ToM development were reviewed. Evidence on signal trial analysis of ToM development paves the way to interpret children's ToM and belief reasoning.

4.1. Speculations on ToM

Children's brain development and modifications in volume and function evidence the occurrences of synaptogenesis and myelination adjustments (Johnson, 2001; Schneider et al., 2022). Effectively, grey- and white-matter volumes undergo substantial structural changes marking brain development (Groeschel et al., 2010; Wilke & Holland, 2003). Consistently, morphometric studies have also illuminated the growth of the dendrites playing an active role in the development of the cerebral cortex (Huttenlocher, 1990). The latency shift is also attributable to age-related changes (Bradford et al., 2020) and the speed of information processing, which may be influenced by synaptic density (DeBoer et al., 2004) and cortical thickness (Sowell et al., 2004). Such postnatal changes take place in cortical substrates toward more skillful processes (Benson et al., 2013) and gradual consolidation (Liu et al., 2009).

During the preschool years, children's first-order ToM develops and helps them to reflect on others' mental states. At 7 years old, they can think and feel about what other is thinking/feeling about (Westby & Robinson, 2014). Subsequently, during the middle to late childhood, 8-11-year-old children understand the third-order ToM. Experiments have presented that ToM development mostly occurs in rTPJ and dMPFC (Bowman et al., 2019; Gweon et al., 2012; Sabbagh et al., 2009; Saxe et al., 2009). Preschoolers' differences in dMPFC and rTPJ aligned with alpha power may yield differences in ToM maturation (Sabbagh et al., 2009; Wellman & Liu, 2004) relating as closely as possible to their vocabulary skills and EF (Sabbagh et al., 2009). Moreover, the EEG rhythms testify to the neural underpinnings of imitation skill and mirror neurons (Mikhailova et al., 2021; Westby & Robinson, 2014) as well as affective ToM (Gallagher & Hutto, 2008). Remarkably, the mu rhythm power contributes to the observation-execution matching system (Lepage & Théoret, 2006). Alongside the concluding remarks on ToM development and the corresponding waveforms, the second part is devoted to making a comprehensive depiction of belief reasoning with the brain's electrical activities.

4.2. Speculations on Belief Reasoning

Belief reasoning undergoes significant developmental changes through childhood by virtue of selective synaptic pruning (Huttenlocher & Dabholkar, 1997; Shaw et al., 2008). The age-related alterations have proved that "an increase in cortical thickness during childhood is followed by cortical thinning dominating adolescence" (Meinhardt et al., 2011, p. 68). This long-lasting structural process supports the maturation of mental states and ToM. Regarding the age-related changes and belief-state processing (consistent vs. inconsistent conditions with FB and TB reasoning), Bradford et al. (2020) point out the egocentric effect. Considering the key role of the egocentric effect, the researchers have specified distinctions among the early (200-400 ms), later (400-600 ms), and final (600-1000 ms) time windows. Intriguingly, the egocentric bias factor manipulated the second time window yet, not the early and final ones. Belief-related changes in brain potentials are particularly evident at medial frontal and temporal sites (Meinhardt et al., 2011).

Moreover, the developmental mechanisms favor the occurrence of belief reasoning before desire reasoning (Bowman et al., 2012). In this regard, Bowman et al. highlighted the undeniable roles of mental-state decoding and mental-state reasoning in 7-8-year-old children. The former concept refers to the "online attribution of mental states to individuals", and the latter presents "using representations of individuals' mental states in order to predict and make judgments about their actions" (p. 12). In particular, they found that the P2 component pertains to three mental states: automatic detection, encoding, and categorization processes. The P2 component is also evident in the studies on PT reasoning (Kühn-Popp et al., 2013). A wealth of converging evidence shows that P2 can indicate an attentional system and detection of salient stimuli (Corbetta et al., 2008), implying that in children, attention orientation and reorientation processes are prerequisites for understanding differences between their own beliefs and the protagonist's behaviors.

Given the influential role of the attention process, the P3b activity in the TPJ informs a context-updating process (Donchin & Coles, 1988). That is, children update their mental representations during FB reasoning since they should effectively decouple reality from the mental state (Liu et al., 2004; Meinhardt et al., 2011). This reinforces the finding that the P3b activity in the rTPJ exhibits the process of reasoning about others' beliefs together with the process of conceptual updating in facing unexpected conditions (Drover, 2014; Sabbagh et al., 2009). In particular, subsequent to the P3b component, there is a trace of slow-wave activity emerging on account of conceptual load costs (Sabbagh et al., 2009). In fact, it is believed that perceptual and conceptual difficulties increase the positive slow wave amplitude in the centro-parietal site (Ruchkin et al., 1988). Moreover, the subjective classification of conceptual operations leads to the increased P3 amplitude in the Pz (Ruchkin et al., 1988). Furthermore, electrical potentials also support the finding that the P3 component is also evident among adults, yet with a major milestone in interpretation (Drover, 2014). In adults, the component evidences an understanding of the agent's beliefs, while it marks a lack of representational understanding in preschoolers. This shows the possibility that 4-5-year-old children are in the early developing stage of implicit FB understanding. Topographical differences and durations indicate that children employ various cognitive strategies to solve FB tasks (Meinhardt et al., 2011). Overall, the literature on functional neural specializations connected to the trajectory of ToM development is unanimous in the idea that ToM reasoning is a developmental phenomenon (Bowman et al., 2019).

In sum, this review study highlighted the temporal neural underpinnings of ToM development aligned with relevant mental and metarepresentational functions and sub-functions. Neural plasticity makes the human brain susceptible to developmental changes (Casey et al., 2000; Johnson, 1999), leading to the presentation of questions and debates about the processing time of functions. The present review addressed EEG- and ERP-based studies in normal children; however, ToM development in children with mental and developmental disorders remains unknown. Moreover, future review studies are suggested to extend the focus beyond the EEG/ERP studies and delve into multimodal methods for delineating spatial information together with high temporal resolution data.

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