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Quality of maternal behaviour during infancy predicts functional connectivity between default mode network and salience network 9 years later

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ABSTRACT

Infants' experiences are considered to determine to a large degree the strength and effectiveness of neural connections and fine tune the development of brain networks. As one of the most pervasive and potent relational experiences of infancy, parent-child relationships appear to be prime candidates to account for experience-driven differences in children's brain development. Yet, studies linking parenting and functional connectivity are surprisingly scarce, and restricted to the connectivity of limbic structures. Accordingly, this longitudinal study explored whether normative variation in the quality of early maternal behaviour predicts the functional connectivity of large-scale brain networks in late childhood. Maternal mind-mindedness and autonomy support were assessed with 28 children when they were 13 and 15 months old respectively. When children were 10 years of age, children underwent a resting-state functional MRI exam. Functional connectivity was assessed between key regions of the default mode network (DMN), salience network (SN), and frontal-parietal central executive network (CEN). Results revealed that higher mind-mindedness and autonomy support predicted stronger negative connectivity between DMN and SN regions. These findings are the first to provide preliminary evidence suggestive of a long-lasting impact of variation within the normative range of early maternal behaviour on functional connectivity between large-scale brain networks.

1. Introduction

Brain development is driven by genetic factors, but also occurs as a function of environmental influences, in such a way that many brain maturation processes are determined by complex interactions between children and their environment (Fox et al., 2010; Greenough et al., 1987; Huttenlocher, 2002). As such, early relational experiences are thought to have a critical impact on child brain development, and are posited to influence the structure and functioning of the brain well beyond the first years of life (Belsky and De Haan, 2011; Cicchetti, 2016). However, much of the empirical knowledge about the impact of early relational experience on brain development is based on the study of extremely adverse experiences, suggesting that neglect, maltreatment, and caregiving deprivation can lead to abnormal brain maturation that may profoundly affect child cognitive and socio-emotional development (Cicchetti, 2016; De Bellis and Zisk, 2014; Hart and Rubia, 2012; Tottenham, 2014). The generalisability of these findings is, however, limited to clinical or otherwise high-risk populations, and it remains unclear whether normative variations in relational experience influence child brain development (Belsky and De Haan, 2011).

Parent-child relationships are among the most pervasive and potent relational experiences of childhood. The quality of early caregiving relationships forecasts diverse child outcomes such as social and emotional adjustment (Thompson, 2016), cognitive development (Bernier et al., 2012; Tamis-Lemonda et al., 2001), and academic achievement (Raby et al., 2015). Some have argued that such consequences are likely attributable to the intermediate effect of early caregiving relationships on the brain structures that underlie socio-emotional and cognitive processes (Belsky and De Haan, 2011; Gunnar et al., 2006; Tottenham, 2014). Yet, empirical work demonstrating the beneficial effects of

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positive parenting on children's brain development is surprisingly scarce. To date, only a few studies have provided evidence for prospective links between normative variation in the quality of early parenting behaviour and child brain morphology or function. Positive parenting in early childhood predicts structural brain development in later childhood, as indicated by larger total, grey matter, and hippocampal volumes (Kok et al., 2015; Luby et al., 2012). Functionally, higher levels of positive maternal behaviour when children are 5 months of age are associated with higher frontal resting neural activity, measured via electroencephalography at 10 and 24 months of age, suggesting more advanced functional brain development (Bernier et al., 2016).

Infants' day-to-day experiences are considered to determine to a large degree which synaptic connections persist and are strengthened by frequent use, and which are eliminated due to under-activity (Huttenlocher, 1979; Kolb et al., 2014; Singer, 1995). Consequently, caregiving relationships should influence the strength and effectiveness of neural connections and thus fine tune the development of brain networks. The development of the connectivity between the amygdala and the prefrontal cortex (PFC) is affected by extreme caregiving adversity (Gee et al., 2013), but also by normative variations in caregiving (Thijssen et al., 2017). In addition, early life stress, even at moderate levels (e.g., stress caused by non-physical conflict between parents), may induce long-lasting changes in the development of functional brain networks (Graham et al., 2015a, 2015b). Yet, current knowledge on the effect of the quality of parenting behaviour on brain functional connectivity in typically developing children is restricted to connectivity with limbic structures (Rifkin-Graboi et al., 2015; Thijssen et al., 2017), and putative caregiving influences have not been explored in other large-scale networks.

There exist a number of indicators of the quality of parenting behaviour during parent-infant interaction. Two in particular have been shown to promote multiple facets of child cognitive and socio-emotional adjustment: (1) mind-mindedness, representing parents' tendency to consider their child as someone who has his/her own mental states, and to comment appropriately on the child's ongoing mental activity (Meins, 1997), and (2) autonomy support, consisting of behaviours that encourage children's independent problem solving, choice, and participation in decisions (Grolnick and Ryan, 1989). Mind-mindedness and autonomy support have both been shown to contribute to children's executive functioning (Bernier et al., 2010; Meuwissen and Carlson, 2015), socio-emotional competence (Matte-Gagné et al., 2015), social adaptation (Joussemet et al., 2005), theory of mind (Kirk et al., 2015; Meins et al., 2013), and empathy (Centifanti et al., 2016), and are therefore crucial aspects of parenting related to child cognitive and social development.

Given their involvement in specific cognitive and socio-emotional processes shown to be predicted by mind-mindedness and autonomy support in previous work (i.e., executive functioning, socio-emotional competence, social adaptation, and theory of mind), three brain networks are of particular interest in relation to these parental behaviours: (1) the default mode network (DMN), comprised of the posterior cingulate cortex (PCC), the ventromedial prefrontal cortex (vmPFC) and the angular gyri, is involved in introspective processing, social cognition (e.g., theory of mind, moral cognition), and affective cognition (Andrews-Hanna et al., 2010; Buckner et al., 2008); (2) the frontal-parietal central executive network (CEN), anchored in the dorsolateral prefrontal cortex (dlPFC) and posterior parietal cortex (PP), plays an important role in executive functions (Menon, 2011; Seeley et al., 2007); and (3) the salience network (SN), including the anterior insula (AI) and the dorsal anterior cingulate cortex (dACC), is involved in the detection of salient stimuli and the initiation of cognitive control by influencing activation of the CEN and the DMN (Menon, 2011; Menon and Uddin, 2010; Seeley et al., 2007). In both adults and children, these three networks work simultaneously during executive tasks (Bressler and Menon, 2010; Takeuchi et al., 2013), social tasks (Chiong et al., 2013; Eggebrecht et al., 2017; Rilling et al., 2008; Xiao et al., 2016), and cognitive control tasks (Dwyer et al., 2014; Kelly et al., 2008). Thus, we hypothesized that parental mind-mindedness and autonomy support would be specifically associated with connectivity of these networks.

Menon (2013) suggested that the DMN, CEN and SN are "the three most prominent networks to be examined from a development perspective" (Menon, 2013 p.631), and that analysis of the connectivity within and across these networks provides unique insight into the maturation of core neurocognitive systems. The progressive refinement of these three networks and their interplay throughout childhood leads to gradually more mature cognitive and socio-emotional functioning (Menon, 2013; Rubia, 2013). The reconfiguration (segregation and integration) of the DMN, CEN and SN during child development likely supports the maturation of flexible cognitive control processes (Dwyer et al., 2014; Menon, 2013; Uddin et al., 2011) and social abilities (Eggebrecht et al., 2017; Xiao et al., 2016).

The present longitudinal study examined whether maternal mind-mindedness and autonomy support during mother-infant interactions predicted the intrinsic (resting) functional connectivity within and between three core brain networks (DMN, CEN, SN) in late childhood. We hypothesized that higher-quality maternal behaviour during mother-infant interactions, as indexed by higher levels of mind-mindedness (at 13 months of age) and autonomy support (at 15 months), would predict more mature brain connectivity when children were 10 years old, as reflected by adult-like patterns of functional connectivity within and between the DMN, CEN and SN.

2. Material and methods

2.1. Participants

Participants included in the present study (N = 28) were followed annually as part of a larger longitudinal prospective cohort project investigating early relational predictors of several facets of child development (Bernier et al., 2010). Here, we report on the quality of maternal behaviour (mind-mindedness and autonomy support) assessed during infancy, and resting-state functional magnetic resonance imaging (rs-fMRI) data collected when children were 10 years of age. The study was approved by the local human research ethics committee and all families provided written informed consent for participation.

Families were recruited from birth lists randomly generated by the Ministry of Health and Social Services. Inclusion criteria were full-term pregnancy (i.e., at least 37 weeks of gestation) and the absence of any known disability or severe delay in the infant. When children were 10 years of age, they were invited to undergo a magnetic resonance imaging (MRI) exam including an rs-fMRI sequence. Inclusion criteria for the MRI study were the absence of neurological or psychiatric disorders, traumatic brain injury, psychoactive medication, and standard MRI contraindications. Of the 64 families approached for the current study, 39 (60.94%) agreed to participate. However, four (6.25%) of these children were not eligible due to standard MRI exclusion criteria (e.g., wearing braces); thus, 35 children underwent the MRI exam (54.69%). There were no sociodemographic differences between the 35 children who underwent the MRI exam and the 29 who did not in terms of family income, parental age, education, ethnicity, language, or child sex (see Table 1, all *ps* > .21).

Of the 35 families who took part in the MRI study, four were subsequently excluded because the child had a diagnosis of anxiety disorder (1) or attention deficit hyperactivity disorder and received psychoactive medication (3). In addition, the rs-fMRI data of three children were excluded due to significant motion (translation > 2.5 mm or rotation > 2.5 degrees). Therefore, data from 28 children (17 girls and 11 boys, $\chi 2$ (1) = 1.29; p = .26) and their mothers were used in the analyses. Note that there were no sociodemographic differences between the final sample (n = 28) and the other families in terms of