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Parenting and offspring brain development: What do we know?

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Abstract

Parenting has been robustly associated with offspring psychosocial development, and these effects are likely reflected in brain development. However, the claim that parenting influences offspring brain development in humans, as measured by structural and functional Magnetic Resonance Imaging (MRI), is subject to numerous methodological limitations. To interpret the state of the parenting and brain development literature, we review these limitations. Four limitations are common. First, most literature has been cross-sectional. Where longitudinal, studies rarely included multiple assessments of brain structure or function, precluding measurement of actual brain development. Second, parenting has largely been measured via self- or parent-report, as opposed to observational assessment. Third, there has been a focus on extreme forms of developmental adversity which do not necessarily lie on a continuum with normative parenting. Fourth, although not a limitation per se, studies have generally focused on negative as opposed to positive parenting behaviours. While not all studies are subject to all these limitations, the study of parenting in relation to offspring brain development is in its infancy.

Keywords: Parenting; brain development, MRI, fMRI.

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Parenting and child brain development: What do we really know?

It is widely acknowledged that parents have a formative influence on their children's psychosocial development (Baumrind, 1991; Belsky & de Haan, 2011; Bradley & Vandell, 2007; McLeod, Weisz, & Wood, 2007; Rose, Roman, Mwaba, & Ismail, 2017; Waite, Whittington, & Creswell, 2014). Indeed, adverse parenting influences children's psychological development in general (Bradley & Vandell, 2007) and their risk for psychopathology in particular (e.g., Collins, Maccoby, Steinberger, Hetherington, & Bornstein, 2000; McLeod, Weisz, & Wood, 2007; McLeod, Wood, & Weisz, 2007). Adoption studies suggest that these effects are not entirely due to shared genes (see Plomin et al., 2008; Belsky & de Haan, 2011; Kriebel & Wenzel, 2011). Interventions that modify parenting also show effects on children's mental health (Yap et al., 2016). As such, it is well-established that parenting influences offspring psychological development. Given these robust effects, numerous studies have sought to understand the neural bases of these influences. Indeed, environmental influences causing persistent psychosocial changes during the developmental period are likely reflected in moderation of structural and functional brain development. Numerous studies have therefore sought to understand the potential influence of individual differences in parenting specifically, and developmental experiences in general, on offspring brain development as this will further our understanding of the neural bases of the influence of parenting on adolescent psychosocial development. However, much of this literature suffers from one or more thematic limitations.

In this review, "brain development" refers to change in brain structure or function over time from one baseline assessment to another assessment at an interval several months or greater, thereby requiring two or more structural or functional brain assessments over time. Where studies do not examine brain development according to this definition, for example in cross-sectional studies, we refer to associations between parenting and offspring brain structure or function. We note that "cross-sectional" refers to a single-time-point study in which parenting and brain structure or function were assessed concurrently. "Longitudinal" refers to studies in which parenting was assessed at one time point and brain structure or function was assessed at a later time point, whether that was a single assessment or multiple assessments. In some studies, brain structure was assessed at baseline; this refers to an initial MRI acquisition that was followed by another at a later time point. Studies to date tend to focus on retrospective or cross-sectional designs (e.g., Goff et al., 2013; Hanson et al., 2012). Among the handful of longitudinal studies, few have measured brain structure or function at repeated time points in order to examine actual brain *development* over time (e.g., Callaghan et al., 2019; Fava et al., 2018; Guyer et al., 2015; Herringa et al., 2016). Similarly, studies have also largely employed self-reports instead of observational measures (e.g., Holmes et al., 2018; Rao et al., 2010), and use self-reports to assess parenting experiences retrospectively (e.g., Teicher et al., 2004; Thomason et al., 2015). Additionally, research has largely focused on the effects of extreme developmental adversity such as institutional rearing, trauma, maltreatment, or neglect (e.g., Walsh et al., 2014; Whittle et al., 2013), as opposed suboptimal but normative parenting.. Where studies have examined normative parenting (e.g., Whittle et al., 2014), these studies have largely focused on maternal rather than paternal influences. Many of these studies also focused on these influences from a range of sources (e.g., childhood adversity or stress in general) as opposed to focusing on parenting per se (e.g., Tottenham et al., 2011; Van der Werff et al., 2013). Another limitation is that the majority of studies have examined the effects of negative parenting as compared to positive parenting, which may have effects independently of negative parental behaviours (e.g., Boecker et al., 2014; Chaplin et al., 2019). Relatedly, no research has examined interactions

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between negative and positive parenting in order to examine whether one may moderate or buffer the effect of the other.

Aims: Given the heterogeneity in this nascent field, rather than review whether parenting influences specific aspects of brain structure or brain function, we aim to review the methodologies employed in this field to demonstrate what we can or cannot conclude about parenting and offspring brain development, as measured via magnetic resonance imaging (MRI) and functional MRI (fMRI). Specifically, the most important gaps in this field reviewed in this paper are 1) a reliance on cross-sectional and/or retrospective methodologies, 2) the use of self- or parent-reports instead of observational methods, 3) a focus on extreme adversity as opposed to normative parenting, and 4) a focus on negative rather than positive parenting.

For excellent reviews pertaining to specific parenting practices and the development of specific neural circuits, such as emotion and reward processing circuitry we refer the reader to recent work dedicated to this question (e.g., Kujawa et al., 2020; Tan et al., 2020). We also do not provide a detailed overview of naturalistic child and adolescent brain development as this has been covered in numerous excellent reviews (e.g., Belsky & de Haan, 2011; Grayson & Fair, 2017; Tamnes et al., 2018; Vijayakumar et al., 2018). Briefly, these reviews highlight patterns of increases in cortical growth stemming from axonal and synaptic generation over childhood followed by cortical thinning via pruning of synapses across adolescence until they reach adult levels, with substantial regional differences in these processes. These developmental changes likely provide maturational windows or sensitive periods such that adverse developmental experiences may be particularly influential on brain development at certain ages (see Hensch, 2004 for a review). For example, prefrontal regions develop the most slowly in the brain, and therefore may be sensitive to developmental influences from childhood through early adulthood, when the prefrontal cortex (PFC) is more fully mature (Dahl, 2004; Hensch, 2004; Luby et al., 2019). While we suspect that parenting has a highly influential effect on offspring brain development, we recognize that a range of other intertwined factors, such as socioeconomic status (Whittle et al., 2017), adverse events outside the parent-child relationship (Luby et al., 2019), and other interpersonal factors such as peer relationships (Lee et al., 2020) are likely influential as well.

Methods

In this review, we examine the limitations to the literature on parenting and offspring brain development, including during infancy, childhood, and adolescence, drawing on the substantial literature on parenting and child development that is not directly concerned with brain development. We include studies that assess early childhood stress or adversity broadly, as measures in these studies typically include content assessing experiences with parents. Moreover, studies included in this review examined associations of parenting with offspring brain structure and function, as assessed via structural MRI and functional MRI (fMRI), respectively. There are multiple studies examining parenting and offspring brain function as assessed via electroencephalography (EEG; e.g., Bernier et al., 2016; Meyer et al., 2015; see Maupin et al., 2015 for a review). This review focuses instead on fMRI as a measure of brain function given it has substantially higher spatial resolution than EEG, and can therefore more precisely examine function in specific brain regions whereas EEG does not identify function in specific regions of the brain as accurately as fMRI. Maupin et al. (2015) also provide an excellent review of research examining associations between parenting and offspring brain function assessed via EEG.

The papers reviewed here examined brain grey matter development including structure, volume, and thickness in a range of brain regions while functional studies employed a range of fMRI tasks (e.g., resting state, emotion processing, reward processing, to name a few). The vast majority of the literature in this field has focused on brain development as assessed via structural MRI or fMRI, while only a handful of studies have examined structural brain connectivity via diffusion tensor imaging (DTI). Moreover, all DTI-based studies to date have focused on extreme adversity in early childhood and assessed early life adversity, deprivation, or maltreatment, as oppose to focusing on parenting per se (Choi et al., 2009; Huang et al., 2012; Hanson et al., 2013; Behen et al., 2009; Eluvathingal et al., 2006; Govindan et al., 2010). Sheikh et al. (2014) provide one exception, although they examined interactions between parenting and children's cortisol reactivity and did not report main effects of parenting on offspring brain structural connectivity. DTI-based studies are therefore not included in this review.

In this scoping review, dates searched ranged up to August 2020. Databases searched included PubMed, Psyc Info, Psyc Articles, ISI Web of Science, and Google Scholar. Search terms queried in the title, abstract, or keywords included "parenting" or "parent-child relationships" or "developmental predictors" or "developmental influences" or "childhood adversity" or "early adversity" AND "child brain development" or "adolescent brain development" or "offspring brain development" or "child brain function" or "adolescent brain function" or "child brain structure" or "adolescent brain structure" or "offspring brain function" or "offspring brain structure." Reference sections of retrieved articles were also examined for any relevant publications that were not found in databases. We also include studies that involve parental deprivation, such as studies of children raised in institutional care, given their implications for the effects of a lack of parental caregiving. In total, 78 studies (Table 1) were

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found that examined relations between either parenting or childhood adversity/stress in general and offspring brain structure or function. Given that the papers reviewed here may have one or more, but not necessary all, the limitations introduced above, some studies are discussed in multiple sections of this review. Throughout, we discuss a handful of studies as illustrative examples of the limitations we outline, although we do not aim to thoroughly discuss every paper listed in Table 1.

Table 1.

Methodological summary of studies in this review.

Citation	Cross-sectional vs Longitudinal	If Longitudinal, repeated measures imaging?	Functional or structural	Parenting measure (parent-report, child report,	Normative parenting versus extreme adversity?	Negative versus positive parenting

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				observational). And was it concurrent or retrospective?		
Barbosa et al. (2018)	Cross-sectional		Functional	Self-report (parent)	Normative	Negative and positive
Bernier et al. (2018)	Longitudinal	No	Structural	Observational, concurrent	Normative	Positive
Boecker et al. (2014)	Longitudinal	No	Functional	Self-report	Adversity	Negative
Brody et al. (2019)	Longitudinal	No	Functional	Self-report	Normative	Positive
Burghy et al. (2012)	Longitudinal	No	Functional	Self-report (parent)	Normative	Negative
Butterfield et al. (2020)	Longitudinal	No	Functional	Self-report	Normative	Positive
Callaghan et al. (2017)	Longitudinal	No	Functional	Self-report & observational, concurrent	Normative	Negative & Positive
Callaghan et al. (2019)	Longitudinal	No	Functional	Parent report	Adversity	Negative
Chaplin et al. (2019)	Cross-sectional		Functional	Observation, concurrent	Normative	Negative
Choi et al. (2009)	Cross-sectional		Structural	Self-report	Adversity	Negative
Dannlowski et al. (2012)	Cross-sectional		Structural	Self-report	Adversity	Negative
Dégeilh et al. (2018)	Longitudinal	No	Functional	Observational, concurrent	Normative	Positive
Dillon et al. (2009)	Cross-sectional		Functional	Self-report	Adversity	Negative
Fareri et al. (2017)	Cross-sectional		Functional	Parent report	Adversity	Negative

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Fava et al. (2018)	Longitudinal	No	functional	Self-report (parent)	Adversity	negative
Gee et al. (2013)	Cross-sectional		Functional	Self-report (parent)	Normative	Negative
Goff et al. (2013)	Cross-sectional		Functional	Parent report & child report	Adversity	Negative
Graham et al. (2015)	Cross-sectional		Functional	Self-report (parent)	Normative	Negative
Guyer et al. (2015)	Longitudinal	No	Functional	Self-report (parent)	Normative	Negative
Hanson et al. (2012)	Cross-sectional		Structural	Self-report (child)	Normative	Negative
Hanson et al. (2015)	Cross-sectional		Functional	Self-report	Adversity	Negative
Hanson et al. (2015)	Cross-sectional		Structural	Self-report (child)	Adversity	Negative
Heim et al. (2013)	Cross-sectional		Structural	Self-report	Adversity	Negative
Herringa et al. (2013)	Longitudinal	No	Functional	Self-report (child)	Adversity	Negative
Herringa et al. (2016)	Longitudinal	No	Functional	Self-report (parent)	Adversity	Negative
Holmes et al. (2018)	Longitudinal	No	Functional	Self-report (child)/child report	Normative	Positive
Jian et al. (2020)	Longitudinal	No	Functional	Self-report (child)	Normative	Negative and Positive
Kok et al. (2015)	Longitudinal	No	Structural	Observational	Normative	Positive
Kopala-Sibley et al. (2018)	Longitudinal	No	Functional	Observational, concurrent	Normative	Negative and Positive
Lee et al. (2014)	Cross-sectional		Functional	Self report	Normative	Negative

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Lee et al. (2016)	Cross-sectional		Structural	Self-report	Adversity	Negative
Lee et al. (2018)	Cross-sectional		Structural	Self-report (child)	Adversity	Negative
Luby et al. (2012)	Longitudinal	No	Structural	Parent-report and observation, concurrent	Normative	Positive
Luby et al. (2013)	Longitudinal	No	Structural	Observation, concurrent	Normative	Positive
Lupien et al. (2011)	Cross-sectional		Structural	Self-report	Normative	Negative
McCrory et al. (2011)	Cross-sectional		Functional	Self-report	Adversity	negative
McCrory et al. (2013)	Cross-sectional		Functional	Self-report	Adversity	Negative
McLaughlin et al. (2014)	Cross-sectional		Structural	Observational (Institutionalization)	Adversity	Negative
Mehta et al. (2009)	Cross-sectional		Structural	Self-report	Adversity	Negative
Merz et al. (2019)	Cross-sectional		structural	Self-report (parent)	Normative	Negative
Morgan et al. (2014)	Longitudinal	No	Functional	Self-report (parent) and observation, concurrent	Normative	Positive
Mueller et al. (2010)	Cross-sectional		Functional	Observation (Institutionalization)	Adversity	Negative
Ohashi et al. (2017)	Cross-sectional		Structural	Self-report	Adversity	Negative
Pagliaccio et al. (2015)	Longitudinal	No	Functional	Parent report	Adversity	Negative

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Philip et al. (2013)	Cross-sectional		Functional	Self-report (child)	Adversity	Negative
Philip et al. (2013)	Cross-sectional		Functional	Self-report	Adversity	Negative
Pozzi et al. (2019)	Cross sectional		Functional	Observational, concurrent & self-report (parent)	Normative	Negative
Pozzi et al. (2020)	Longitudinal	No	Functional	Observational, concurrent & parent/child-report	Normative	Negative
Rao et al. (2010)	Longitudinal	No	Structural	Self-report	Normative	Positive
Richmond et al. (2019)	Cross-sectional		Functional	Observational, concurrent	Normative	Negative
Romund et al. (2016)	Cross-sectional		Functional	Self-report (child)	Normative	Positive (maternal support)
Roth et al. (2018)	Cross-sectional		Structural	Self-report	Adversity	Negative
Schneider et al. (2012)	Cross-sectional		Structural & functional	Self-report	Normative	Positive
Sheridan et al. (2012)	Cross-sectional		Structural	Observation (Institutionalisation	Adversity	Negative
Soe et al. (2016)	Longitudinal	No (?)	Functional	Self-report (parent)/ parent report	Normative	Negative
Stein et al. (1997)	Cross-sectional		Structural	Self-report	Adversity	Negative
Taylor et al. (2006)	Cross-sectional		Functional	Self-report	Normative	Negative
Teicher et al. (2004)	Cross-sectional		Structural	Self-report	Adversity	Negative
Thijssen et al. (2017)	Cross-sectional		Functional	Observation, concurrent	Normative	Negative
Thomason et al. (2015)	Cross-sectional		Functional	Self-report (child)	Adversity	Negative

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Tomoda et al. (2009)	Cross-sectional		Structural	Self-report	Normative	Negative
Tomoda et al. (2011)	Cross-sectional		Structural	Self-report	Normative	Negative
Tottenham et al. (2010)	Cross-sectional		Structural	Self-report	Adversity	Negative
Tottenham et al. (2011)	Cross-sectional		Functional	Observation, concurrent	Adversity	Negative
Tyborowska et al. (2018)	Longitudinal	No	Structural	Observational, concurrent & parent report	Normative	Negative
Van der Werff et al. (2013)	Cross-sectional		Functional	Self-report	Adversity	Negative
Vidal-Ribas et al. (2019)	Longitudinal	No	Functional	Parent-report	Normative	Negative- early life stress (e.g. sickness, exposure to violence, family accomplishments)
Walsh et al. (2014)	Cross-sectional		Structural	Self report	Adversity	Negative
Wang et al. (2019)	Longitudinal	Yes	Functional	Observational, concurrent	Normative	Positive
Whittle et al. (2008)	Cross-sectional		Structural	Observational, concurrent	Normative	Negative
Whittle et al. (2009)	Cross-sectional		Structural	Observational, concurrent	Normative	Negative
Whittle et al. (2011)	Cross-Sectional		Structural	Observational, concurrent	Adversity	Negative
Whittle et al. (2013)	Longitudinal	No	Structural	Observational, concurrent	Normative	Positive

Whittle et al. (2013)	Longitudinal	Yes	Structural	Self-report	Adversity	Negative
Whittle et al. (2016)	Longitudinal	Yes	Structural	Observational, concurrent	Normative	Negative
Whittle et al. (2017)	Longitudinal	No	Structural	Self-report, retrospective	Adversity	Negative
Whittle et al. (2017)	Longitudinal	Yes	Structural	Observational, concurrent	Normative	Positive
Williamson et al. (2009)	Cross sectional		Functional	Self-report (child)	Adversity	Negative
Wolf & Herringa (2016)	Cross sectional		Functional	Self-report	Adversity	Negative
Yap et al. (2008)	Cross-Sectional		Structural	Observational, concurrent	Normative	Negative
Zhu et al. (2019)	Cross-sectional		Functional	Self-report (child)	Adversity	Negative

We recognize that many of these studies stem from longitudinal cohort studies that were not originally designed to examine parenting and brain development, per se; for example, many studies were originally designed to examine neural markers of risk for psychopathology or other psychosocial outcomes (e.g., Pagliaccio et al., 2015). Indeed, methodological limitations described here are common in a range of fields relevant to psychology and neuroscience (Fox et al., 2007; Kazdin, 2016; McMahon & Bernier, 2017). We conclude by discussing the state of knowledge in this field and ways in which research may be strengthened by outlining ideal methods to establish an effect of parenting behaviour on offspring brain development. Throughout this review, we use the broad terms “negative parenting” or “suboptimal parenting” to refer to an array of specific parenting behaviours, such as hostility, low warmth, or maltreatment, as well as specific maladaptive parenting styles such as authoritarianism, permissiveness, and physical or psychological control.

Results

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Cross-sectional versus longitudinal studies of parenting and offspring brain development.

The methods of the studies reviewed here are summarized in Table 1. The majority of the literature on the associations of parenting with child brain structure or function is cross-sectional as opposed to longitudinal. Cross-sectional designs preclude examining within individual change, and therefore brain *development*, and cannot establish the direction of the relationship between parenting and offspring brain function. Few studies have conducted repeated measures of brain imaging. Indeed, of the studies surveyed (Table 1), 48 were cross sectional**.** Of the 30 longitudinal papers (9 structural MRI and 21 fMRI), only six included assessed parenting and brain structure or function and then conducted MRI scans at a later time point (Whittle et al., 2017; Whittle et al, 2016; Whittle at al., 2013; Tyborowska at al., 2018; Pagliaccio et al., 2015; Wang et al., 2019*)*. Only one of these studies (Wang et al., 2019) assessed brain function at multiple waves, although they did not examine actual change over time in brain function.

This paucity of longitudinal studies examining development of brain function or structure examined at repeated time points presents a substantial limitation. That is, the absence of an initial measure of brain structure or function precludes drawing meaningful conclusions about how the brain changes over time. Additionally, the lack of an initial timepoint limits the ability to address the issue of reverse causality as children's biology influences their behaviour. It is well-established that the parent-child relationship is bi-directional and children have a substantial influence on the parenting they receive (Belsky, 1984; Burke, Pardini, & Loeber, 2008; Combs-Ronto, Olson, Lunkenheimer, & Sameroff, 2009; Hawes, Dadds, Frost, & Hasking, 2011; Pardini, Fite, & Burke, 2008; Kopala-Sibley et al., 2017). By not assessing children's brain structure or function at baseline concurrently with the parenting assessment, effects of parenting at baseline on later brain structure or function could be due to an unmeasured association between offspring brain function or structure and parenting at baseline. Indeed several recent studies that conclude there are likely effects of parenting on brain development are subject to this limitation, as parenting was assessed at baseline followed by neuroimaging in the offspring at a later time point (Butterfield et al., 2020; Dégeilh, Bernier, Leblanc, Daneault, & Beauchamp, 2018; Kok et al., 2015; Taylor, Eisenberger, Saxbe, Lehman, & Lieberman, 2006; Guyer et al., 2015; Jiang et al., 2020; Kopala-Sibley et al., 2020).

Two studies to date have conducted fMRI scans in children at baseline and follow-up.. Wang and colleagues (2019) examined the effect of maternal sensitivity, assessed observationally during a mother-infant play task, on hippocampal functional connectivity in children. Children underwent resting-state fMRI scans at four and a half and again at six years of age. Maternal sensitivity at six months of age was associated with right anterior hippocampal (aHPC) functional connectivity with sensorimotor and cognitive control networks in children at both ages. Results suggest that early childhood stress stemming from a lack of maternal sensitivity may have a lasting impact on the development of functional connectivity in brain regions linked to memory processes, stress-related processing, and affect. However, Wang et al. (2019) did not examine development (i.e., change over time) of brain function from age 4 to 6 years. Moreover, associations found may be due to an unmeasured association between infant brain function and parenting during infancy. Additionally, given that parenting styles and behaviours tend to be relatively stable over time (e.g., Kopala-Sibley et al., 2017; Dallaire & Weinraub, 2005), maternal sensitivity when children underwent fMRI scans was potentially similar to when children were infants. It is therefore possible that effects of parenting on brain function stemmed from much more recent parenting behaviours, making it unclear whether parenting had long-lasting impacts in this study.

Pagliaccio et al. (2015) examined the effects of early life stress on functional connectivity of children’s amygdalae in a longitudinal study about environmental and neural risk for psychopathology in youth and was not originally designed to specifically examine parenting and offspring brain development. Children completed fMRI scans between the ages of seven and twelve and again between the ages of nine and 14, although this study focused on the age nine to 14 time point. Stressful life events, including items relevant to parenting, were assessed retrospectively via a semi-structured interview. An increased incidence of adverse life experiences predicted weakened connectivity of the amygdala with the anterior cingulate cortex at the age 9 to 14 timepoint, which in turned was associated with anxiety symptoms. Similarly, Jiang et al. (2020) found that adolescent self-reported negative maternal parenting in early adolescence predicted enhanced amygdala-prefrontal functional connectivity in mid-adolescence. Results suggest that adverse childhood events, including events relevant to parenting, as well as adolescent reports of normative parenting (Jiang et al., 2020) are associated with altered corticolimbic functional connectivity in late childhood and adolescence, and that this altered connectivity may be a neural mechanism linking adverse childhood experiences to later anxiety symptoms (Pagliaccio et al., 2015). However, not examining actual change over time in amygdala functional connectivity precludes strong conclusions about effects of early life stress on functional brain development over time. Additionally, the focus in Pagliaccio et al. (2015) on adversity in general rather than parenting specifically means it is difficult to disentangle effects of parents versus other sources of stress, while the retrospective assessment of adversity also presents a limitation, as discussed below.

Retrospective child- or parent-report versus observational measures of parenting

The preponderance of research in this field has employed retrospective self reports versus observational assessments of parenting behaviour (Table 1). Retrospective reports are biased by a variety of factors such as the current mood or mental health of the respondent, the interval between the occurrence of an event and the reporting of that event, and interpersonal factors that have since occurred between the parent and child (see Hardt & Rutter, 2004). It is therefore unclear whether retrospective self-reports provide an accurate and unbiased measure of parenting.

For example, a recent meta-analysis (Baldwin et al., 2019) reviewed 16 studies comprising 25,471 participants. These were studies in which children and youth had been followed over time and had concurrent, documented histories of experiencing maltreatment, as determined by child protective services, police records, or parent, child, or teacher reports. Across these studies, youth also completed retrospective self-reports of recalled maltreatment experiences. Baldwin et al. (2019) then examined the concordance between prospective and retrospective accounts of maltreatment. They found very poor agreement (kappa = .18) and concluded that prospective and retrospective accounts of maltreatment identify different groups of individuals. More troubling, 52% of youth with contemporaneously documented histories of maltreatment did not retrospectively report it, while 56% of youth who retrospectively reported maltreatment did not have concordant prospective observations. In a commentary on this study, Widom (2019) notes that these results are consistent with decades of research that has found that retrospective reports of experiences corroborate poorly with contemporaneous assessment and documentation (Yarrow et al., 1970; Brewin et al., 1993; Henry et al., 1994; Hard & Rutter, 2004). They conclude that the use of retrospective measures precludes conclusions about whether particular experiences have causal influences on outcomes and that retrospective reports constitute “existential recollections” rather than memories of factual events (Widom, 2019).

Brewin et al. (1993), in reviewing research linking retrospective reports to current psychopathology, have suggested three possible reasons for these problems: low reliability and validity of autobiographical memory in general, the presence of general memory impairment associated with psychopathology, and the presence of specific mood-congruent memory biases

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associated with psychopathology. Given that psychopathology will be neurally mediated, it is likely that retrospective accounts of developmental experiences will be biased by current brain structure and function. Associations between current brain structure and function and retrospective accounts of developmental experiences, including parenting, therefore suggest a link between those experiences and brain structure or function, but should be interpreted cautiously in terms of what information they provide regarding effects of those experiences on brain development.

Moreover, child and parent reports of parenting do not correspond well with each other (Sessa et al., 2001), while laboratory-based observations of parent-child interactions tend to correspond well with in-home observations of parent-child interactions (Zaslow et al., 2006). There is also evidence that home and lab observational measures are better predictors of child psychosocial outcomes than parent or child reports (Zaslow et al., 2006). Zaslow et al. (2006) examined mother-child dyads and included mother reports of parenting as well as in-home observations and structured lab-based observations of parent-child interactions. Children were reassessed four years later and included mother, child, and teacher reports as well as direct assessments. First, they found that in-home and lab-based observations of parenting were consistently significantly related to each other, but that neither converged with maternal reports of parenting. Second, they found that observational methods of assessment showed stronger associations with 4-year outcomes (social skills and academic achievement) compared to maternal reports. This suggests parental or self-reports of parenting alone may not provide a comprehensive picture of a child’s parenting experiences. We should note, however, that while laboratory or home-based assessments are arguably the gold-standard at present, they are also subject to limitations including ecological validity, transient influences such as mood states, and

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restrictions in the range of affect and behavior elicited in the parent and child. It is therefore likely that parent-reports and laboratory-based observations provide unique perspectives.

An exclusive focus on child- or parent-reports is an issue in a wide range of studies. Indeed, of the studies examined (Table 1), the large majority employed retrospective self report measures (e.g., the Childhood Trauma Questionnaire), while 21 utilized observational measures such as a videotaped interaction tasks performed in a lab setting.

Of the studies employing observational methods (Table 1), 14 examined brain structure and 8 examined brain function (Kopala-Sibley et al., 2020, Dégeilh, Bernier, Leblanc, Daneault, & Beauchamp, 2018, Wang et al., 2019, Tottenham et al., 2011, Mueller et al., 2010, Thijssen et al., 2017, Morgan, Shaw, & Forbes, 2014, and Chaplin et al., 2019). Of these eight that employed an observational approach to measuring parenting and examined brain function, four merit particular attention as they were longitudinal and assessed parenting at one time point and brain function at a later time point (Kopala-Sibley at al., 2018; Dégeilh, Bernier, Leblanc, Daneault & Beauchamp, 2018; Wang et al., 2019; Morgan et al., 2014).

Kopala-Sibley et al. (2020) assessed parenting towards three-year-old children via lab-based observations and maternal reports. Children then completed fMRI scans between the ages of 10-11. During an emotion processing task, during exposure to sad relative to neutral faces, maternal hostility at age 3, assessed observationally, predicted increased negative functional connectivity between the medial prefrontal cortex as well as the insula and frontal operculum and the amygdala. Maternal regulation on the other hand, assessed via maternal report, predicted greater functional connectivity within cingulo-frontal brain regions during a monetary reward task. Maternal hostility predicted increased negative connectivity between the left ventral striatum and right inferior frontal gyrus and right posterior orbital frontal cortex during the same condition. These results suggest that parenting in early childhood may have lasting effects on the development of brain function linked to emotion processing and reward processing.

Dégeilh et al. (2018) assessed the developmental effects of higher quality parenting behaviour when children were between 13 and 15 months old on brain function nearly a decade after the initial assessment. This was done with a sample of 28 children. High quality maternal behaviour was quantified by video taped interactions of free play between the parent-child dyad. At ten years of age, the children underwent an fMRI scan while at rest. Higher quality maternal behaviour early in development predicted increased negative resting state functional connectivity between the salience and default mode networks. They suggest that high quality maternal behaviour promotes development of these networks by priming development of social and emotional capabilities.

Similarly, Wang et al. (2019) showed that maternal sensitivity was associated positively with the right anterior hippocampus' functional connectivity with the sensorimotor network and negatively with the right anterior hippocampus' functional connectivity with the top-down cognitive control network. At 6 years of age, early childhood maternal sensitivity was linked positively with the right anterior hippocampus' functional connectivity with the visual-processing network. Morgan et al. (2014) found that elevated maternal warmth in early childhood, assessed observationally, was associated with decreased medial prefrontal cortex activation when experiencing reward loss and reward gains when offspring were 20 years old. Greater maternal warmth also predicted greater caudate date activation to reward loss.

Taken together, results confirm a longitudinal link between early childhood parenting and later (as much as 20 years later) function in a range of brain regions. In particular, parenting in early childhood is linked to function in corticolimbic regions and circuits involved in emotion

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and reward processing (Kopala-Sibley et al., 2020; Morgan et al., 2014) as well as subcortical-cortical functional connectivity in regions linked to memory, stress, and affect processes (Jiang et al., 2020; Wang et al., 2019) in later childhood or adolescence. Parenting during infancy and early childhood is also linked to functioning of salience and default mode networks, circuits involved in emotional perspective taking, prosocial behaviour, theory of mind, and empathy (Dégeilh et al., 2018; Graham et al., 2015). While these studies are all highly informative and overcome the limitations associated with retrospective self- or parent-reports of parenting by assessing parenting observationally, they did not control for baseline brain function, and as such conclusions regarding brain development over time are limited. They also cannot account for potential effects of baseline child brain function influencing parenting.

Focus on extreme forms of adversity rather than normative experiences.

Another limitation of this body of work is the focus on extreme forms of developmental adversity, such as abuse, neglect, or institutional rearing, to the exclusion of examining the effects of normative, albeit potentially maladaptive parenting. Given that most children will not experience maltreatment (Wildeman et al., 2014), this presents a problem in terms of generalizability of the findings. That is, evidence that abuse or maltreatment may influence brain structure or function provides limited information about how non-maltreating but suboptimal forms of parenting may influence the developing brain. That is, extreme and normative parenting behaviors do not lie on a continuum; effects of extreme behaviors do not therefore provide information on the effects of normative parenting. Moreover, despite the fact that the large majority of children will experience variability in the “normative” (i.e., non-maltreating) parenting they receive, our knowledge of how the experiences of most children affect brain development is surprisingly limited. To date, a handful (Table 1) of studies have examined the effects of normative parenting in infants, children, or adolescents (e.g., Butterfield et al., 2020; Dégeilh et al., 2018, Jiang et al., 2020; Kok et al., 2015; Lee, Siegle, Dahl, Hooley, & Silk, 2014, Guyer et al., 2015, Bernier et al., 2018; Kopala-Sibley et al., 2020 Wang et al., 2019, Brody et al., 2019, Schneider et al., 2012, Romund et al., 2016, Thijssen et al., 2017;Whittle et al., 2008, 2009, 2014, 2016, 2017; Yap et al., 2008). Five were cross-sectional and seven were longitudinal in that they either measured parenting at one time point and brain structure or function at a later time point, or they measured parenting at baseline and then included repeated measures of neuroimaging. Of the longitudinal papers, three examined brain structure and three examined brain function.

For example, as described, Dégeilh et al., (2018) found associations between maternal parenting assessed observationally in early childhood and late childhood brain function in offspring. Guyer et al. (2015) found that parent-reports of authoritarian parenting styles were associated with altered ventrolateral PFC responses to peer rejection, with effects being moderated by adolescent temperament. Kopala-Sibley et al. (2020) found that maternal hostility, assessed observationally when children were three years old, predicted more negative amygdala connectivity during exposure to sad relative to neutral faces with frontal and parietal regions as well as more negative left ventral striatal connectivity during monetary gain relative to loss feedback with the right posterior orbital frontal cortex and right inferior frontal gyrus when children were 10-11 years old. Maternal regulation predicted enhanced cingulo-frontal connectivity during monetary gain relative to loss feedback.

These studies suggest a potential effect of suboptimal but normative parenting in early childhood on brain regions involved in emotion processing and regulation (Guyer et al. 2015; Kopala-Sibley et al., 2020) and theory of mind and emotional perspective taking from infancy to late childhood (Dégeilh et al., (2018). However, Guyer et al. (2015) relied upon maternal reports and employed a cross-sectional design, while neither Dégeilh et al. (2018) nor Kopala-Sibley et al. (2020) examined actual brain development over time and could not adjust for baseline brain function.

An important exception comes from a series of studies from Whittle and colleagues (Whittle et al., 2013, 2016). In these studies, adolescents completed structural MRI scans at multiple time points over the course of adolescence. At the baseline time point, parents and children completed a problem solving and event-planning interaction task from which maternal positive and aggressive behaviour were coded. Adjusting for baseline brain structure, they found that positive parenting predicted change over time in amygdala volumes and PFC thickness. These studies provide strong evidence of the effects of normative parenting on structural brain development over time, particularly as it relates to emotional processing, affect regulation, and risk for psychopathology such as depression and anxiety. To our knowledge, these are the only studies to employ a longitudinal design with repeated neuroimaging assessments and to assess a normative range of parenting behaviours using lab-based observational methods. They therefore provide the strongest evidence to date for a causal role of parenting in offspring brain development, although naturalistic research cannot establish causality.

A focus on negative versus positive parenting.

Studies to date have generally focused on negative parenting behaviours as opposed to positive (e.g., warm, sensitive, and supportive) parenting behaviours. Yet, positive parenting behaviours are associated with a range of beneficial outcomes for children including improved academic performance, more adaptive temperament, and lowered risk for psychopathology (Beckwith et al., 1992, Eshel et al., 2006, Landry et al., 2008). Positive parenting is additionally important to consider given that positive and negative parenting do not lie on a spectrum; rather, they are at least somewhat orthogonal (Whittle et al., 2014). For example, a lack of negative parenting (e.g., harshness, criticism, control) does not necessarily imply high levels of positive parenting. Multiple levels of positive and negative parenting may exist together in various combinations and permutations. As such, understanding their unique effects on offspring brain development is highly important, as the impacts of positive and negative parenting behaviors on offspring brain development are unlikely to lie on a continuum with simple linear or additive combinations' effects on brain development. This additionally results in a lack of research on the potential effects of positive parenting behaviour on offspring brain development and how positive parenting may mitigate or buffer (i.e., moderate) exposure to negative parenting.

Eighteen studies have examined positive parenting, of which eight were structural and eleven were functional (one included both structure and function). Of the eight structural studies, seven were longitudinal, but only two examined brain structure at multiple time points. Of the eleven functional studies, ten were longitudinal, but no studies have examined brain function at multiple time points in order to examine change over time.

For example, Morgan et al. (2014), discussed above, found that maternal warmth, assessed observationally in early childhood was associated with altered neural response to rewards versus loss when offspring were 20 years of age, although they did not control for baseline brain function. Similarly, Wang et al. (2019), already discussed, did not examine change over time in brain function. While Schneider et al. (2012) found maternal affiliation was positively associated with hippocampal and orbitofrontal gray matter density and with caudate reactivity to reward, they employed self-report measures in a cross-sectional design. In their studies, Whittle and colleagues (Whittle et al., 2013; 2016) found that, even controlling for

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negative or aggressive parenting, positive maternal parenting as assessed during the problem-solving interaction task predicted change in adolescent amygdala volume and prefrontal cortical thickness (Whittle et al., 2013). They also found that positive parenting buffers the effects of lower socioeconomic status on amygdala and prefrontal cortex development (Whittle et al., 2017). The integration of observational measures of both positive and negative parenting with repeated measures of brain structure renders the evidence from these studies very methodologically strong. We are not aware of any research that features these methodological strengths that examined offspring brain function rather than structure. Other work has similarly found links between maternal support, care, responsiveness, or positive parenting generally during early childhood and children's hippocampal volumes (Luby et al., 2012), anterior cingulate and thalamus volumes (Rao et al., 2010), global cortical thickness (Frye et al., 2010), orbitofrontal cortex activation in adolescents during an emotion processing task (Pozzi et al., 2020), and strength of structural covariance networks (Richmond et al., 2018). Thus, multiple single time point studies suggest that positive parenting is linked to adolescent brain structure and function in range of regions including but not limited to regions relevant to affect, memory, and emotion processing, while two studies have found that positive parenting in adolescence influences development over time in prefrontal and limbic regions (Whittle et al., 2013, 2016). Whittle et al. (2016) provide the first evidence to our knowledge that positive parenting may buffer the effects of low socioeconomic status on prefrontal and limbic brain development. However, the majority of other studies included a single time point and did not examine brain development over time.

Discussion

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We reviewed methodological limitations in the literature pertaining to associations between parenting and offspring brain structure and function as well as brain development over time. We also include studies examining developmental adversity in general as these studies, while not focusing directly on parenting, typically include adverse experiences with parents (e.g., maltreatment or neglect) in their measures of adversity. As noted, many of these studies were not originally designed to examine parenting and offspring brain development. Nevertheless, studies to date offer important insights into potential influences of parenting on offspring brain development. In particular, of the various brain regions examined in the studies included in this review, the majority have focused on subcortical, including limbic, striatal regions, and hippocampal regions, as well as prefrontal cortical regions (e.g., Butterfield et al., 2020; Kopala-Sibley et al., 2020; Morgan et al., 2014; Whittle et al., 2013; Pagliaccio et al., 2015; Pozzi et al., 2020; Wang et al., 2019). This may be in part because at least some of these studies stemmed from broader cohort studies whose primary focus was understanding child and adolescent risk factors for adverse behavioural outcomes, in particular psychopathology such as depression and anxiety (e.g., Pagliaccio et al., 2015; Whittle et al., 2013, 2016).

However, studies have also found associations between parenting in infancy, childhood, or adolescence and global cortical thickness (Frye et al., 2010), total grey matter volume (Kok et al., 2015), functioning in the occipital lobe in adolescents (Pozzi et al., 2020), and large scale functional brain networks such as functional connectivity of the default mode and salience networks in late childhood (Dégeilh et al., 2018; Graham et al., 2015). Research confirms associations between self-reported and retrospectively recalled adverse developmental experiences and suboptimal parenting and offspring brain structure and function, in particular in limbic, striatal, and prefrontal region structure, function, and functional connectivity during a range of fMRI tasks. A smaller, but rapidly growing, body of evidence suggests that parenting at one time point, such as early childhood or adolescence, is associated with brain function in emotion and reward processing regions at a later time point, even as much as eight (Kopala-Sibley et al., 2020) to 20 years (Morgan et al., 2014) later. Other studies have confirmed links between parenting in infancy or early childhood and function in large scale brain networks later in childhood (Dégeilh et al., (2018) and regions linked to memory, stress, and affect processes (Wang et al., 2019). These studies suggest a potentially long-lasting impact of parenting on offspring brain function. Only two studies of which we are aware (Whittle et al., 2013, 2016) showed that parenting, observationally assessed within a normative range during adolescence, predict brain development. Consistent with prior research suggesting a longitudinal link between parenting and limbic and prefrontal brain structure or function, Whittle et al. (2013, 2016) confirm that parenting influences change over time in amygdala and prefrontal brain structure.

Results to date may also have implications for our understanding of the importance of developmental timing in terms of the effects of parenting on offspring brain development. The handful of studies that have examined parenting and brain structure or function in infants and children (Bernier et al., 2018; Kopala-Sibley et al., 2020; Degeilh et al., 2018; Graham et al., 2015; Wang et al., 2019; Soe et al., 2016) confirm postulations that this age-range is a period during which the developing brain may be particularly vulnerable to developmental insults (Luby et al., 2019; Teicher et al., 2018). However, results from the current review confirm an association between parenting and late childhood and adolescent brain structure and function, as well. This is consistent with a few studies to examine the influence of age on the impacts of maltreatment on brain structure. For example, Teicher et al. (2018) found that adult male hippocampal volume was associated with neglect prior to the age of seven. Similarly, Luby et al.

(2019) found that adverse childhood events in the preschool period were associated with adolescent hippocampal volumes, although they note some regional specificity in associations of childhood adversity at different ages and brain structure. However, Teicher et al. (2018) also found that, in females, abuse during the adolescent, but not childhood period, predicted altered hippocampal volumes. Prior research as well as results from the current review therefore support infancy, childhood, and adolescence as particularly important developmental stages during which parenting and developmental adversity more broadly may impact brain development.

Despite this, conclusions regarding effects of parenting on offspring brain development should likely remain tentative based on the preponderance of research to date. That is, the majority of this research is limited first by issues pertaining to cross-sectional designs and second by the use of retrospective self-reports. Cross-sectional designs cannot examine within individual change in brain structure or function over time, and therefore do not directly inform development. Nevertheless, researchers often correlate age with brain function or structure to infer potential developmental effects. For example, a negative correlation of age with volume in a particular brain region may suggest that that brain region decreases in size with age. Some studies have employed these methods and incorporated parenting and have found that parenting moderates the association between age and brain function (e.g., Thijssen et al., 2017), from which they suggest parenting may alter the development of brain function. However, cross-sectional studies of age-related differences are confounded by potential cohort effects, for example, cohort differences in exposure to technology or social media, differences in cultural expectations around behaviour or academic performance, or cohort differences in parenting behaviours which may change over generations. This possibility is well-established in other branches of developmental psychology, such as the study of personality development (e.g., Kopala-Sibley et al., 2013; McCrae et al. 1999).

The use of retrospective assessments are also potentially problematic as they may be inaccurate or biased by current mental health, personality, or brain structure or function (Baldwin et al., 2019). Related to this, a reliance on self-reports is a common limitation in this literature given that child and parent-reports of parenting converge only modestly, and neither converge well with in-home or lab-based observations of parentings, which themselves correspond well (Zaslow et al., 2006). Steen et al. (2007) also note that longitudinal studies in which brain structure is measured at repeated time points provide substantially more power to detect changes in brain structure relative to cross-sectional studies comparing different groups of individuals. The majority of studies also examine more extreme forms of adversity such as maltreatment, abuse, or institutionalization. Longitudinal studies with repeated measures of brain structure or function, and that use gold-standard methods for assessing parenting within a normative range are rare, with the exception of two studies that examined parenting and structural brain development (Whittle et al., 2013, 2016). To our knowledge, no studies have examined effects of parenting on the development of brain function over time, which presents a substantial limitation to our knowledge in this field.

While not all studies are subject to all these limitations, studies examining the link between parenting and structural or functional brain development typically suffer from one or more, with only a few exceptions (Whittle et al., 2013; 2016). Thus, our knowledge of the effects of parenting on offspring brain development remains in its infancy, although it has evolved substantially since Belsky and de Haan (2011) concluded it was in a pre-conception phase.

Finally, it is important to note the challenges in studying parenting and offspring brain development. First, it requires following a relatively large cohort in which both parent and child participate at multiple time points over the course of development. This is inherently difficult given challenges around recruitment and retention, especially when both parent and child need to participate. Second, MRI scans are costly, and pediatric MRI poses substantial challenges given factors such as that children may move more in the scanner relative to adults, thereby making some data unusable, while other children may be claustrophobic, for example. Dental hardware provides another challenge in MRI in youth, as this can cause significant artifacts. The study of brain development requires at least two scans over time per participant to model linear change, and at least three scans to model non-linear change (e.g., quadratic; four scans would b required to model cubic growth). It is well-established that the many brain regions do not develop linearly (e.g., Vijyakumar et al., 2016), and parenting may influence brain development in a non-linear manner. It will be important to examine this possibility in future research.

Third, fMRI tasks designed to elicit certain cognitive processes in the brain (e.g., emotion processing), may not be appropriate or repeatable at different developmental stages, rendering examination of long-term change in specific aspects of brain function difficult as these may require different tasks at different ages. This is a common challenge in developmental research as assessing within-subject change requires identical measurement methods at each time point, although measures appropriate for one age are often not appropriate for another. Fourth, while observational assessments of parenting are arguably the gold-standard method of assessing parenting, these are time consuming to conduct and to code, with coders requiring extensive training. There are also multiple factors other than parenting such as socioeconomic status, community violence, school quality, sibling relationship, and peer relationships, to name a few, that may affect brain development or interact with parenting to affect brain development. Assessing all of these in any one study will be a challenge. As such, it is unsurprising that many of the studies to date stem from broader studies that were not originally specifically designed to assess parenting and offspring brain development (e.g., Pagliaccio et al., 2015).

Future directions

Addressing the limitations discussed above in future research would be a major step towards strengthening this field of inquiry. Emphasizing longitudinal designs with repeated measures of brain structure and function, a broadened focus on the full range of parenting behaviour, including positive parenting, coupled with the increased use of observational methods and potentially integration of observational methods with child- and parent-reports, would allow researchers to more fully understand the influences of parenting on adolescent functional brain development. There are, additionally, several other avenues for future research.

Regarding the notion of integration multiple sources of information about parenting, a promising potential method for doing so is the use of structural equation modeling (SEM; Hox & Bechger, 1998; Schumacker & Lomax, 2004). In brief, SEM assumes that observed variables (e.g., parent-reports of parenting, lab-based observations of parenting) represent only one part of the underlying "true" construct (i.e., parenting). SEM then extracts the shared variance between these observed indicators of the underlying construct to create a latent construct. On the assumption that no one method of assessing parenting measures all of the true variance in parenting, this approach may be a viable and important approach to measuring parenting in future studies. This approach has been used successfully to create latent assessments of children's temperament from mother- and father-reports and lab-based observations of young children's temperament as well as from mother-, father-, and child reports of temperament in older children (Kopala-Sibley et al., 2018).

We are unaware of any experimental research in this field. Indeed, even the most methodologically sound naturalistic study cannot establish a causal effect of parenting on offspring brain development. This is despite a substantial body of evidence that interventions meant to ameliorate parenting are effective in improving youth outcomes such as mood and anxiety disorders (see Yap et al., 2016 for a meta-analysis) as well as externalizing symptoms (Kazdin, 2005; Ogden & Hagen, 2008).By assigning groups of parents to different intervention conditions and then examining offspring brain development over time, researchers would be able to establish causal effects of parenting on children's brain development. This would, moreover, further our knowledge of the neural bases of how parenting influences children's psychosocial development.

The vast majority of this literature has also examined effects of maternal rather than paternal parenting. Indeed, fathers are less likely to participate in developmental psychology research than mothers (Parent et al., 2017). However, given that paternal behaviours towards children are robustly linked to children's psychopathological outcomes (see Moller et al., 2016 for a meta-analysis), understanding influences of paternal parenting on offspring brain development is likely important.

A related issue is that there may be particular windows during development during which the brain is particularly susceptible to effects of parenting on its development. Moreover, it is well-documented that different brain regions develop at different rates (e.g., Brown, 2017). As such, it will be highly important for future research to be hypothesis driven and carefully consider the timing both of assessments of parenting and of offspring brain structure and function, as these may vary depending on the child's developmental stage as well as the brain region of interest. Given relatively more rapid development of subcortical structures in childhood (e.g., Muftuler et al., 2011), repeated sampling of structural and functional MRI may need to be closer together in early childhood, with intervals lengthening as the child ages through later childhood and adolescence. Yet, based on evidence to date, it is unclear if there are ideal intervals at which to space assessments of parenting and brain structure or function. Directly relevant to this question is Herting et al. (2018) who reviewed the test-retest stabilities of brain function assessed by fMRI in studies that included two or more time points of fMRI. Studies included samples ranging in age from late childhood to early adulthood, and fMRI assessment intervals ranged from approximately 9 weeks to up to 3.5 years (Table 2 in Herting et al., 2018). Function across a range of brain regions assessed via a range of fMRI tasks showed that test-reliabilities ranged widely, from poor (Intraclass correlation; ICC <.40) to excellent (ICC > .75). While they note that test-retest reliabilities are influenced by range of factors including but not limited to head motion, data processing methods, practice effects, and scanner parameters, test-retest reliabilities are also an indicator of how stable a construct is over time (see Brandes et al., 2020; Kopala-Sibley et al., 2018). That is, a lower ICC may suggest greater within-subject variability over time. Greater variability may suggest at what intervals brain function changes substantially, and it is vital to understand what component of variability is methodological as opposed to developmental. Future research should consider the rate at which brain structure and function changes at different developmental stages in order to understand the optimal intervals for the assessment of parenting and brain structure and function in offspring.

Although noted by Belsky and de Haan (2011) nine years ago, there have yet to be any studies examining reciprocal or bi-directional relationships between parenting and offspring brain development. Indeed, it is well-established that children influence the environment around them (Belsky, 1984; Belsky & Jaffee, 2006). There is also substantial evidence that while parenting influences children's behaviour and mental health, children's behaviour and psychopathological symptoms influence parenting (Kopala-Sibley et al., 2017). For example, Patterson's (1982; Granic & Patterson, 2006; Patterson, DeBaryshe, & Ramsey, 1989) model of coercive interactions describes a pattern in which parents either provide a directive or refuse a child's request, thereby increasing the child's distress and aversive behaviors such as screaming or crying. Ultimately the parent accedes to the child's wishes in order to avoid the further escalation of undesirable child behaviors and possible public embarrassment. The child then learns that increased negative behaviors will eventually be rewarded, while the parent learns that acquiescing to the child's desires will immediately decrease the aversive behaviors. This is one example of a process that likely occurs not only in moment-to-moment interactions but also on a larger scale of child psychopathology symptoms and parenting practices. These effects and behaviours will be mediated via children's brain development; however, no research has tested this possibility. Relatedly, there is substantial evidence that parenting behaviours change over time. For example, maternal harsh parenting towards their infant or young child tends to increase from birth through the age of 3 (Kim et al., 2010), while overreactive parenting increases and parenting self-efficacy decreases over the first few years of a child's life (Lipscomb et al., 2011). Similarly, parental support tends to decrease over the course of adolescence (Wang et al., 2011), although there will be substantial variability in these trajectories across parents. However, it is unknown how within-subject trajectories of parenting, as opposed to between subject differences, relate to offspring brain development.

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Finally, naturalistic research in humans cannot establish a causal effect of parenting on offspring brain development, no matter how strong the study design. As such, numerous researchers have employed animal models to study this issue using experimental designs not possible in humans. Indeed, numerous rodent studies suggest a potential influence of parental care and offspring brain development. For example, maternal licking/grooming behaviour towards pups are associated with altered prefrontal cortex function (Van Hasselt et al., 2012) while maternal presence versus absence is associated with altered amygdala function (Moriceau & Sullivan, 2006). Maternal licking/grooming behaviour is also associated with altered hypothalamic-pituitary-adrenal axis function in rat pups (Liu et al., 1997;) while pups that were handled early in life compared to those that were not showed altered hippocampal function (Francis & Meaney, 1999). As such, findings from both naturalistic human research and experimental animal research will be highly important in furthering our understanding of effects of parenting on offspring brain development.

Conclusions

We reviewed the methodological limitations in the literature on associations between parenting and offspring brain structure and function as well as brain development over time with a view to understanding what we can and cannot conclude. While this is now a sizeable literature, cross-sectional designs, retrospective self-report measures of parenting, a lack of multiple time points of neuroimaging, a focus on extreme adversity as opposed to normative parenting, and an emphasis on negative rather than positive parenting limit our knowledge regarding the effect of parenting on child brain development.

In their review of the literature on parenting and offspring brain development, Belsky and de Haan (2011) concluded that the field is not even in its infancy but is rather at a pre-conception

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stage. The current review suggests that the field has made important advancements in the past nine years and substantially informed our understanding of effects of parenting on offspring brain development, but, due in part to limitations in the methodology of research in this area, there are still substantial gaps in our understanding of how parenting influences offspring brain development.

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