A Narrative Review of Methodological Considerations in Magnetic Resonance Imaging of Offspring Brain Development and the Influence of Parenting

Shiv Bhanot[1], Signe Bray[2,3,4,5], Alexander McGirr[1,3,5], Kate Lee[6] and Daniel C. Kopala-Sibley[1,3,4,5]*

[1] Department of Psychiatry, University of Calgary, Calgary, AB, Canada, [2] Department of Radiology, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada, [3] Mathison Centre for Mental Health Research and Education, University of Calgary, Calgary, AB, Canada, [4] Alberta Children's Hospital Research Institute, Calgary, AB, Canada, [5] Hotchkiss Brain Institute, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada, [6] Department of Psychology, York University, Toronto, ON, Canada

Parenting has been robustly associated with offspring psychosocial development, and these effects are likely reflected in brain development. This hypothesis is being tested with increasingly rigorous methods and the use of magnetic resonance imaging, a powerful tool for characterizing human brain structure and function. The objective of this narrative review was to examine methodological issues in this field that impact the conclusions that can be drawn and to identify future directions in this field. Studies included were those that examined associations between parenting and offspring brain structure or function. Results show four thematic features in this literature that impact the hypotheses that can be tested, and the conclusions drawn. The first theme is a limited body of studies including repeated sampling of offspring brain structure and function, and therefore an over-reliance on cross-sectional or retrospective associations. The second involves a focus on extremes in early life caregiving, limiting generalizability. The third involves the nature of parenting assessment, predominantly parent- or child-report instead of observational measures which may be more ecologically valid measures of parenting. A closely related fourth consideration is the examination of detrimental versus positive parenting behaviors. While studies with one or more of these thematic limitations provide valuable information, future study design should consider addressing these limitations to determine how parenting shapes offspring brain development.

Keywords: brain development, parenting, MRI, fMRI, child development, adolescence

INTRODUCTION

The brain develops rapidly during infancy, childhood, and adolescence (Belsky and de Haan, 2011; Grayson and Fair, 2017; Tamnes et al., 2018; Vijayakumar et al., 2018), while substantial physical, emotional, and social maturation occurs through dynamic interactions with the environment (Baumrind, 1991; Bradley and Vandell, 2007; McLeod et al., 2007a,b; Waite et al., 2014; Rose et al., 2017). Parents likely play an important role in this process, depending

in part on their behavioral interactions with their child. Indeed, adverse parenting influences children's psychological development in general (Bradley and Vandell, 2007), and their risk for psychopathology in particular (e.g., Collins et al., 2000; McLeod et al., 2007a,b). Interventions that modify parenting also show effects on children's mental health (Yap et al., 2016).

The protracted development of the brain likely provides maturational windows, or sensitive periods, such that specific parental behaviors may be particularly influential on brain development at certain ages (see Hensch, 2004 for a review). 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). While it is well established that parenting influences offspring psychosocial development, the study of how this is reflected in the brain is still a relatively new endeavor with important challenges and discoveries to be made. Thoughtful study design will be crucial to our ability to understand how, when, and in what ways parental behavior is important for offspring brain development.

Recent years have seen a proliferation of studies using neuroimaging to infer relationships between parenting and offspring brain development. Here, we focus on the magnetic resonance imaging (MRI) literature examining parenting behavior and offspring brain structure and function. This is a rapidly evolving field, and therefore our focus is on study design considerations that have important repercussions on the specific hypotheses that can be tested, and conclusions drawn, regarding influences of parenting on offspring brain development. This is crucial for future study design; while no study design is perfect, based on the extant literature, special consideration should be given to four thematic design features that are currently pervasive. These are (1) an overreliance on cross-sectional or retrospective methodologies, (2) a focus on extremes of early life childcare and adversity as opposed to more normative experiences, (3) measuring parenting behaviors with self-report measures to the exclusion of observational methods, and (4) a focus on negative rather than positive parenting.

METHODS

In this review, we examine the literature on parenting and offspring brain development, including during infancy, childhood, and adolescence. "Brain development" refers to studies in which neuroimaging was conducted at multiple time points, thereby examining change over time in brain structure or function. Where studies were cross-sectional or longitudinal such that parenting was assessed at one time point and neuroimaging was conducted at a later single time point, we refer to associations between parenting and offspring brain structure or function, as these studies cannot examine change over time in brain structure or function. We focus on MRI, both structural and functional, as it can be used to repeatedly sample brain dynamics and structure with high spatial resolution. The papers reviewed here examined brain gray matter including 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, and to name a few) and analytic approaches (evoked responses and functional connectivity). Only a handful of studies have examined diffusion tensor imaging (DTI) and all DTI-based studies to date to our knowledge have focused on extreme adversity in early childhood as oppose to focusing on parenting *per se* (Eluvathingal et al., 2006; Behen et al., 2009; Choi et al., 2009; Govindan et al., 2010; Huang et al., 2012; Hanson et al., 2013). 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 white matter structure. DTI-based studies are therefore not included in this review. The literature using other non-invasive tools and approaches has been described elsewhere (Meyer et al., 2015; Bernier et al., 2016; see Maupin et al., 2015).

In this narrative review, dates searched ranged up to May 2021. 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, 82 studies (**Table 1**) were found that examined relations between either parenting or childhood adversity/stress in general and offspring brain structure or function.

A common consideration across many of these studies is that the primary purpose of the research programs from which the data is drawn was not to examine parenting and offspring brain development, *per se*. Instead, parenting was an important secondary endpoint in studies of risk for psychopathology in children and youth.

RESULTS

Cross-Sectional Versus Longitudinal Studies of Parenting and Offspring Brain Development

Given substantial inter-individual differences in brain structure and function, longitudinal designs that control for baseline characteristics are the gold standard for studying developmental processes rather than cross-sectional associations (Crone and Elzinga, 2015). 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. Few studies have conducted repeated measures

of brain imaging. Indeed, of the studies surveyed (**Table 1**), 47 (57.32%) were cross sectional. Of the papers containing longitudinal data (10 structural MRI and 23 fMRI), only 12 (14.63% of all studies) assessed parenting and brain structure or function and then conducted MRI scans at a later time point (Whittle et al., 2013a,b, 2016, 2017; Kok et al., 2015; Pagliaccio et al., 2015; Tyborowska et al., 2018; Wang et al., 2019; Butterfield et al., 2021; Jiang et al., 2021; Pozzi et al., 2021; Suffren et al., 2021), although only five examined brain structural (Whittle et al., 2013a,b, 2016, 2017) or functional development over time (Pozzi et al., 2021).

Cross-sectional studies or studies where parenting is assessed at one time point and brain structure or function assessed at a single later time point provide valuable associations, but they have important limitations. This is particularly so in the study of development, where the research question is related to change in brain structure or function over time. Many associations between parenting and offspring brain structure or function will likely be replicated when subjected to longitudinal repeated measures study designs, however important confounds identified in the developmental psychology literature may also apply to the parenting and offspring brain development literature. For instance, 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 et al., 2008; Pardini et al., 2008; Combs-Ronto et al., 2009; Hawes et al., 2011; Kopala-Sibley et al., 2017). Moreover, given that parenting styles and behaviors tend to be relatively stable over time (e.g., Dallaire and Weinraub, 2005; Kopala-Sibley et al., 2017), it will be important to carefully consider when to measure parenting and offspring brain structure and function to separate acute from persistent effects. 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 a baseline association that has not been accounted for.

A closely related issue is that longitudinal studies with multiple imaging time points are necessary to assess brain development trajectories. Given the marked changes in brain structure and function across development, the interpretation of an association between parenting and brain structure in childhood might be very different than in adolescence. For example, adverse parenting may be associated with reduced cortical thickness in childhood but increased cortical thickness in adolescence. Longitudinal analyses of multiple timepoints of imaging data would be required to test the possibility that while adverse parenting is associated with reduced cortical thickness in childhood, it is also associated with a slower pattern of thinning during adolescence, in contrast to the normal developmental pattern of cortical thickness (Vijayakumar et al., 2016).

Retrospective Child- or Parent-Report Versus Observational Measures of Parenting

An exclusive focus on child- or parent-reports is an issue in a wide range of studies examining associations between parenting and offspring brain structure or function as assessed via MRI or fMRI. Indeed, of the studies examined (**Table 1**), the large majority employed retrospective self-report measures, while 27 (32.92%, including studies of institutionalized children) utilized observational measures such as a videotaped interaction tasks performed in a laboratory setting. Of the studies employing observational methods (**Table 1**), 15 (18.29% of all studies) examined brain structure and 12 (14.63% of all studies) examined brain function. Of these 12 that employed an observational approach to measuring parenting and examined brain function, five (6.25% of all studies) involved longitudinal assessment of parenting at one time point and brain function at a later time point (Morgan et al., 2014; Dégeilh et al., 2018; Wang et al., 2019; Kopala-Sibley et al., 2020; Pozzi et al., 2021).

The major design considerations with self-reported parenting, particularly retrospective self-report, is the confounding effect 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 and Rutter, 2004). It should be noted that while concurrent as opposed to retrospective self-reports are likely less influenced by memory issues, they may still be influenced by current mood, mental health, or recent interpersonal factors between the parent and child. This is not limited to parental self-reports, as child and parent reports of parenting do not correspond well with each other (Sessa et al., 2001; Zaslow et al., 2006). A large body of literature has called into question the validity of retrospective reports of experiences, as these corroborate poorly with contemporaneous assessment and documentation (Yarrow et al., 1970; Brewin et al., 1993; Henry et al., 1994; Hardt and Rutter, 2004).

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 = 0.18) 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. Associations between current brain structure and function and self-reported accounts of developmental experiences, particularly retrospectively, should be interpreted with caution.

A possible solution to this issue is the use of laboratory and/or in-home observations of parent child interactions to quantify parenting behavior. Indeed, laboratory-based observations of parent-child interactions tend to correspond well with in-home observations of parent-child interactions (Zaslow et al., 2006).

TABLE 1 | Methodological summary of studies included in this review.

Citation	Cross-sectional versus longitudinal	If longitudinal, repeated measures imaging?	Functional or structural	Parenting measure (parent-report, child report, observational). And was it concurrent or retrospective?	Normative parenting versus extreme adversity?	Negative versus positive parenting	Sample Size	Age of offspring at parent assessment	Age of child at MRI	Age of child at second MRI
Barbosa et al., 2018	Cross-sectional		Functional	Parent-report	Normative	Negative and positive	88	8–9 years	8–9 years	N/A
Bernier et al., 2018	Longitudinal	No	Structural	Observational, concurrent	Normative	Positive	33	12–15 months	10–11 years	N/A
Boecker et al., 2014	Longitudinal	No	Functional	Self-report	Adversity	Negative	162	3 months to 15 years	Mean = 24.4 years	N/A
Brody et al., 2019	Longitudinal	No	Functional	Self-report	Normative	Positive	119	11–13 years and 16–17 years	25 years	N/A
Burghy et al., 2012	Longitudinal	No	Functional	Parent-report	Normative	Negative	57	1, 4, and 12 months	18 years	N/A
Butterfield et al., 2021	Longitudinal	No	Functional	Self-report	Normative	Positive	30	Mean age: 11.58 years	13.58 years	N/A
Callaghan et al., 2017	Longitudinal	No	Functional	Self-report and observational, concurrent	Normative	Negative and positive	128	12 years	16 years	N/A
Callaghan et al., 2019	Longitudinal	No	Functional	Parent report	Adversity	Negative	102	5–16 years (Time 1); 8–19 years (Time 2)	5–16 years	N/A
Chaplin et al., 2019	Cross-sectional		Functional	Observation, concurrent	Normative	Negative	66	12–14 years	12–14 years	N/A
Choi et al., 2009	Cross-sectional		Structural	Self-report	Adversity	Negative	32	18–25 years	18–25 years	N/A
Dannlowski et al., 2012	Cross-sectional		Structural	Self-report	Adversity	Negative	148	20–57 years	20–57 years	N/A
Dégeilh et al., 2018	Longitudinal	No	Functional	Observational, concurrent	Normative	Positive	28	13–15 months	10 years	N/A
Dillon et al., 2009	Cross-sectional		Functional	Self-report	Adversity	Negative	29	Mean age: 24.58 years (exp); 37.08 years (control)	Mean age: 24.58 years (exp); 37.08 years (control)	N/A
Fareri et al., 2017	Cross-sectional		Functional	Parent report	Adversity	Negative	88	6–18 years	6–18 years	N/A
Fava et al., 2018	Longitudinal	No	Functional	Self-report (parent)	Adversity	Negative	92	<11 years (retrospective)	9–15 years	N/A
Gee et al., 2013	Cross-sectional		Functional	Self-report (parent)	Normative	Negative	89	6.5–17.6 years	6.5–17.6 years	N/A
Goff et al., 2013	Cross-sectional		Functional	Parent report and child report	Adversity	Negative	69	5–15 years	5–15 years	N/A
Graham et al., 2015	Cross-sectional		Functional	Self-report (parent)	Normative	Negative	23	0–12 months	6–12 months	N/A
Guyer et al., 2015	Longitudinal	No	Functional	Self-report (parent)	Normative	Negative	39	7 years	Mean age: 17.89 years	N/A
Hanson et al., 2012	Cross-sectional		Structural	Self-report (child)	Normative	Negative	61	10–13 years	10–13 years	N/A
Hanson et al., 2015a	Cross-sectional		Functional	Self-report	Adversity	Negative	106	11–15 years (Time 1); 13–18 years (Time 2)	11–15 years	13–18 years
Hanson et al., 2015b	Cross-sectional		Structural	Self-report (child)	Adversity	Negative	128	9–14 years	9–14 years	N/A

(Continued)

TABLE 1 | Continued.

Citation	Cross-sectional versus longitudinal	If longitudinal, repeated measures imaging?	Functional or structural	Parenting measure (parent-report, child report, observational). And was it concurrent or retrospective?	Normative parenting versus extreme adversity?	Negative versus positive parenting	Sample Size	Age of offspring at parent assessment	Age of child at MRI	Age of child at second MRI
Heim et al., 2013	Cross-sectional		Structural	Self-report	Adversity	Negative	51	18–25 years	18–25 years	N/A
Herringa et al., 2013	Longitudinal	No	Functional	Self-report (child)	Adversity	Negative	64	18 years	18 years	N/A
Herringa et al., 2016	Longitudinal	No	Functional	Self-report (parent)	Adversity	Negative	132	18–19 years	18–19 years	N/A
Holmes et al., 2018	Longitudinal	No	Functional	Self-report (child)/child report	Normative	Positive	91	11, 12, and 13 years	25 years	N/A
Kok et al., 2015	Longitudinal	No	Structural	Observational	Normative	Positive	191	1–4 years	8 years	N/A
Kopala-Sibley et al., 2020	Longitudinal	No	Functional	Observational, concurrent	Normative	Negative and positive	79	3 years	10 years	N/A
Jiang et al., 2021	Longitudinal		Functional	Self-report, concurrent	Normative	Negative and positive	89	Mean age: 12.67 years	Mean age: 16.03 years	
Lee et al., 2014	Cross-sectional		Functional	Self-report	Normative	Negative	32	9–17 years	9–17 years	N/A
Lee et al., 2016	Cross-sectional		Structural	Self-report	Adversity	Negative	31	Mean age: 16.12 years	Mean age: 16.12 years	N/A
Lee et al., 2018	Cross-sectional		Structural	Self-report (child)	Adversity	Negative	31	Mean age: 16.12 years	Mean age: 16.12 years	N/A
Luby et al., 2012	Longitudinal	No	Structural	Parent-report and observation, concurrent	Normative	Positive	92	3–5 years; 4–7 years	7–13 years	N/A
Luby et al., 2013	Longitudinal	No	Structural	Observation, concurrent	Normative	Positive	145	Time 1: 3–6 years; Time 2: 6–7 years; Time 3: 8–12 years	Time 1: 10.53 years; Time 2: 12.03 years; Time 3: 13.35 years; Time 4: 16.61 years	N/A
Lupien et al., 2011	Cross-sectional		Structural	Self-report	Normative	Negative	38	13 years	10 years	N/A
McCrory et al., 2011	Cross-sectional		Functional	Self-report	Adversity	Negative	43	12 years	12 years	N/A
McCrory et al., 2013	Cross-sectional		Functional	Self-report	Adversity	Negative	41	12 years	12 years	N/A
McLaughlin et al., 2014	Cross-sectional		Structural	Observation (?) – institutionalized	Adversity	Negative	80	6–30 months	8–10 years	N/A
Mehta et al., 2009	Cross-sectional		Structural	Self-report	Adversity	Negative	14	Mean = 16 years	16 years	N/A
Merz et al., 2019	Cross-sectional		Structural	Self-report (parent)	Normative	Negative	66	5–9 years	5–9 years	N/A
Morgan et al., 2014	Longitudinal	No	Functional	Self-report (parent) and observation, concurrent	Normative	Positive	120	18 and 24 months; 10–11 years	20 years	N/A
Mueller et al., 2010	Cross-sectional		Functional	Observation (?) – institutionalized	Adversity	Negative	33	13 years	13 years	N/A
Ohashi et al., 2017	Cross-sectional		Structural	Self-report	Adversity	Negative	122	18–25 years	18–25 years	N/A
Pagliaccio et al., 2015	Longitudinal	No	Functional	Parent report	Adversity	Negative	120	9–14 years	9–14 years	N/A
Philip et al., 2013a	Cross-sectional		Functional	Self-report (child)	Adversity	Negative	27	Exp: 37 ± 10 years; control: 30 + 9 years	Exp: 37 ± 10 years; Control: 30 ± 9 years	N/A
Philip et al., 2013b	Cross-sectional		Functional	Self-report	Adversity	Negative	21	Mean age: 39.7 years (exp); 37.4 years (control)	Mean age: 39.7 years (exp); 37.4 years (control)	N/A

(Continued)

TABLE 1 | Continued.

Citation	Cross-sectional versus longitudinal	If longitudinal, repeated measures imaging?	Functional or structural	Parenting measure (parent-report, child report, observational). And was it concurrent or retrospective?	Normative parenting versus extreme adversity?	Negative versus positive parenting	Sample Size	Age of offspring at parent assessment	Age of child at MRI	Age of child at second MRI
Pozzi et al., 2019	Cross sectional		Functional	Observational, concurrent and self-report (parent)	Normative	Negative	80	8–9 years	9–10 years	N/A
Pozzi et al., 2020	Longitudinal	No	Functional	Observational, concurrent and parent/child- report	Normative	Positive and negative	86	Time 1: 8–9 years; Time 2: 9–10 years	9–10 years	N/A
Pozzi et al., 2021	Longitudinal	Yes	Functional	Observational	Normative	Positive and negative	95	Mean age: 8.4 years	Mean age: 8.4 years	Mean age: 9.9 years
Rao et al., 2010	Longitudinal	No	Structural	Self-report	Normative	Positive	49	Time 1: 4 years; Time 2: 8 years	13–16 years	N/A
Richmond et al., 2019	Cross sectional		Structural	Observational, concurrent	Normative	Positive and negative	145	8 years	8 years	N/A
Romund et al., 2016	Cross-sectional		Functional	Self-report (child)	Normative	Positive	83	13–16 years	13–16 years	N/A
Roth et al., 2018	Cross-sectional		Structural	Self-report	Adversity	Negative	138	9–15 years	9–15 years	N/A
Schneider et al., 2012	Cross-sectional		Structural and functional	Self-report	Normative	Positive	63	Mean age: 14.24 years	Mean age: 14.24 years	N/A
Sheridan et al., 2012	Cross-sectional		Structural	Observation (?) – institutionalized	Adversity	Negative	74	8–11 years	8–11 years	N/A
Soe et al., 2016	Longitudinal	No	Functional	Self-report (parent)/parent report	Normative	Negative	258	6, 18, and 24 months	6 and 18 months	N/A
Stein et al., 1997	Cross-sectional		Structural	Self-report	Adversity	Negative	21	32.0 years	32 years	N/A
Suffren et al., 2021	Longitudinal	No	Structural	Parent-report	Adversity	Negative	94	2.5–9 years	12–16 years	N/A
Taylor et al., 2006	Cross-sectional		Functional	Self-report	Normative	Negative	30	18–36 years	18–36 years	N/A
Teicher et al., 2004	Cross-sectional		Structural	Self-report	Adversity	Negative	166	Mean age: 12.9 years (exp); 11.9 years (control)	Mean age: 12.9 years (exp); 11.9 years (control)	N/A
Thijssen et al., 2017	Cross-sectional		Functional	Observation, concurrent	Normative	Negative	124	6–10 years	6–10 years	N/A
Thomason et al., 2015	Cross-sectional		Functional	Self-report (child)	Adversity	Negative	42	9–15 years	9–15 years	N/A
Tomoda et al., 2009	Cross-sectional		Structural	Self-report	Normative	Negative	45	18–25 years	18–25 years	N/A
Tomoda et al., 2011	Cross-sectional		Structural	Self-report	Normative	Negative	21	18–25 years	18–25 years	N/A
Tottenham et al., 2010	Cross-sectional		Structural	Self-report	Adversity	Negative	78	Mean age: 60–134 months	Mean age: 62–142 months	N/A
Tottenham et al., 2011	Cross-sectional		Functional	Observation, concurrent	Adversity	Negative	44	Mean age: 9 years (exp); 10 years (control)	Mean age: 9 years (exp); 10 years (control)	N/A
Tyborowska et al., 2018	Longitudinal	No	Structural	Observational, concurrent and parent report	Normative	Negative	37	17 years	14 years (Time 1) and 17 years (Time 2) years	N/A

(Continued)

TABLE 1 | Continued.

Citation	Cross-sectional versus longitudinal	If longitudinal, repeated measures imaging?	Functional or structural	Parenting measure (parent-report, child report, observational). And was it concurrent or retrospective?	Normative parenting versus extreme adversity?	Negative versus positive parenting	Sample Size	Age of offspring at parent assessment	Age of child at MRI	Age of child at second MRI
Van der Werff et al., 2013	Cross-sectional		Functional	Self-report	Adversity	Negative	88	39 years	39.0	N/A
Vidal-Ribas et al., 2019	Longitudinal	No	Functional	Parent-report	Normative	Negative-early life stress (e.g., sickness, exposure to violence and family accomplishments)	38	7 years	10 years	N/A
Walsh et al., 2014	Cross-sectional		Structural	Self report	Adversity	Negative	58	17–20 years	17–20 years	N/A
Wang et al., 2019	Longitudinal	Yes	Functional	Observational, concurrent	Normative	Positive	137	6 months	4 and 6 years	N/A
Whittle et al., 2008	Cross-sectional		Structural	Observational, concurrent	Normative	Negative	137	11.4–13.7 years	11.4–13.7 years	N/A
Whittle et al., 2009	Cross-sectional		Structural	Observational, concurrent	Normative	Negative	113	11.4–13.6 years	11.4–13.6 years	N/A
Whittle et al., 2011	Cross-Sectional		Structural	Observational, concurrent	Adversity	Negative	?	Mean = 12.2 years	Mean = 12.2 years	N/A
Whittle et al., 2013b	Longitudinal	Yes	Structural	Observational, concurrent	Normative	Positive	188	12 years	12 years	16 years
Whittle et al., 2013a	Longitudinal	Yes	Structural	Self-report	Adversity	Negative	117	Mean age: 12.6 years (Time 1); 16.4 years (Time 2)	Mean age: 12.6 years	16.4 years
Whittle et al., 2016	Longitudinal	Yes	Structural	Observational, concurrent	Normative	Negative	166	12 years	12 years	16 years (Time 2); 19 years (Time 3)
Whittle et al., 2017	Longitudinal	Yes	Structural	Observational, concurrent	Normative	Positive	177	13 years	13 years	17 years (Time 2); 19 years (Time 3)
Williamson et al., 2009	Cross sectional		Functional	Self-report (child)	Adversity	Negative	32	20–53 years (exp); 21–59 years (control)	20–53 years (exp); 21–59 years (control)	N/A
Wolf and Herringa, 2016	Cross sectional		Functional	PTSD diagnosis (?)	Adversity	Negative	53	8–18 years	8–18 years	N/A
Yap et al., 2008	Cross-Sectional		Structural	Observational, concurrent	Normative	Negative	106	11.4–13.6 years	11.4–13.6 years	N/A
Zhu et al., 2019	Cross-sectional		Functional	Self-report (child)	Adversity	Negative	202	20–25 years	20–25 years	N/A

There is also evidence that home and laboratory observational measures are better predictors of child psychosocial outcomes, including social skills and academic achievement, than parent or child reports (Zaslow et al., 2006). While laboratory or home-based assessments provide unique data on dyadic interactions, they are also subject to limitations including ecological validity, transient influences such as mood states, and 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 complementary information on parent-child relationships. Future research will likely benefit from examining how different measures of parenting converge or differ in their associations with offspring brain structure or function.

Extreme Forms of Adversity Versus Normative Experiences

Numerous studies focused on extreme forms of developmental adversity, such as abuse, neglect, or institutional rearing. This is the case in 39 studies (47.56%, **Table 1**). What is unclear is whether parenting behavior lies on a continuum, and whether a parametric relationship exists along this continuum in order to inform the influences of normative parenting on brain structure and function. Most children will not experience maltreatment (Wildeman et al., 2014), however all children will receive both positive and negative parenting with varying frequency and intensity. Our knowledge of how the parenting experiences of most children affect brain structure or function is somewhat limited. To date, 43 studies (52.43%, **Table 1**) studies have examined the effects of normative parenting in infants, children, or adolescents (e.g., Whittle et al., 2008, 2009; Wildeman et al., 2014; Whittle et al., 2016, 2017; Yap et al., 2008; Schneider et al., 2012; Lee et al., 2014; Guyer et al., 2015; Kok et al., 2015; Romund et al., 2016; Thijssen et al., 2017; Bernier et al., 2018; Dégeilh et al., 2018; Brody et al., 2019; Wang et al., 2019; Kopala-Sibley et al., 2020; Butterfield et al., 2021; Jiang et al., 2021). Twenty-three of these 28 (75%) 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.

This is important, because non-pathological behaviors have been associated with offspring differences in brain structure and function, including variability in parenting styles (Guyer et al., 2015; Dégeilh et al., 2018), maternal hostility (Kopala-Sibley et al., 2020), aggression (Whittle et al., 2013b, 2016), and behavioral regulation (Kopala-Sibley et al., 2020). Further research examining non-pathological parental behavior will be important to determining dose-response relationships between parental behavior and offspring brain development, and how extremes in early life caregiving behaviors can inform our knowledge of potential effects of normative parenting. It will also be important in future research to examine whether adversity versus normative parenting are uniquely associated with offspring brain development.

A Focus on Negative Versus Positive Parenting

The majority of research to date has focused on negative parenting behaviors (**Table 1**). Twenty-two (26.83%) studies have examined positive parenting, of which nine (10.97% of all studies) were structural and 14 (17.07% of all studies) were functional (some included both structure and function and/or both positive and negative parenting). Of the nine structural studies, eight were longitudinal (9.76% of all studies), but only four examined brain structure at multiple time points (Whittle et al., 2013a,b, 2016, 2017; 4.82% of all studies). Of the 14 functional studies, 11 were longitudinal (12.99% of all studies), with one study to date examining change over time in brain function (Pozzi et al., 2021).

This is an important knowledge gap in understanding the impact of parental behaviors on offspring brain structure and function. Positive behaviors including warm, sensitive, and supportive parenting behaviors have been associated with a range of improved psychosocial outcomes in offspring including improved academic performance, more adaptive temperament, and lowered risk for psychopathology (Beckwith et al., 1992; Eshel et al., 2006; Landry et al., 2008). Moreover, positive and negative parenting are not opposite sides of the same coin and do not necessarily lie on a continuum. For example, a lack of negative parenting (e.g., harshness, criticism, and 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 and may be at least somewhat orthogonal (Whittle et al., 2014). The unique contributions of positive and negative parenting behaviors, and their synergies, will be an important design consideration for future studies examining the effects of parenting on offspring brain structure and function.

DISCUSSION

We reviewed thematic design features that have important scientific ramifications for our understanding of how parenting influences offspring brain structure and function. 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. The purpose of this review is to highlight areas within this rapidly evolving field that would benefit from next-generation approaches and methodologies. When possible, future studies should consider longitudinal, multi-wave acquisitions of both parenting and offspring neuroimaging, the inclusion of observational assessments and normative parenting behaviors, as well as consideration of positive as well as negative parenting behaviors.

Though many of the studies we review were not originally designed to examine parenting and offspring brain structure or function *per se*, they have provided 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, and hippocampal regions,

as well as prefrontal cortical regions (e.g., Whittle et al., 2013a; Morgan et al., 2014; Pagliaccio et al., 2015; Wang et al., 2019; Kopala-Sibley et al., 2020; Pozzi et al., 2020; Butterfield et al., 2021). 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 behavioral outcomes, in particular psychopathology such as depression and anxiety, as well as effects of parenting on child emotional and behavioral regulation (e.g., Whittle et al., 2013a, 2016; Pagliaccio et al., 2015). Thus, these regions may have been the focus of numerous studies given links between their structure or function and child mental health and behavior.

However, studies have also found associations between parenting in infancy, childhood, or adolescence and global cortical thickness (Frye et al., 2010), total gray matter volume (Kok et al., 2015), functioning in the occipital lobe in adolescents (Pozzi et al., 2020), functional connectivity in corticolimbic regions (Jiang et al., 2021), and large-scale functional brain networks such as functional connectivity of the default mode and salience networks in late childhood or adolescence (Graham et al., 2015; Dégeilh et al., 2018; Pozzi et al., 2021). 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 three studies of which we are aware (Whittle et al., 2014, 2016; Pozzi et al., 2021) 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. (2013b), Whittle et al. (2016) confirm that parenting predicts change over time in amygdala and prefrontal brain structure. Recently, Pozzi et al. (2021) show that parenting predicts change over time in resting state functional connectivity in older children.

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 (Graham et al., 2015; Soe et al., 2016; Bernier et al., 2018; Dégeilh et al., 2018; Wang et al., 2019; Kopala-Sibley et al., 2020) confirm postulations that this age-range is a period during which the developing brain may be particularly vulnerable to developmental insults (Teicher et al., 2018; Luby et al., 2019). However, results from the current review confirm an association between parenting and late childhood and adolescent brain structure and function, as well (Teicher et al., 2018; Luby et al., 2019). This highlights the need for dedicated research efforts throughout development to understand the impacts of parenting on offspring brain structure and function at different developmental stages.

Challenges in Dissecting Parenting Effects on Offspring Brain Development

There are unique challenges to this field of research. First, it requires following a relatively large cohort in which both parenting and child brain structure or function are assessed at multiple time points over the course of development. This will be necessary to examine associations between parenting and trajectories of offspring brain development. Assessing parenting and offspring brain structure of function at multiple time points will also be necessary to examine potential bi-directional associations between parenting and offspring brain development. This is inherently difficult given challenges around recruitment and retention, especially when both parent and child need to participate, although some evidence suggests that longitudinal designs are more efficient for the study of change in brain structure, suggesting that smaller sample sizes may be adequate (Steen et al., 2007).

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 between-subject rank-order change (i.e., a change in a participant's standing relative to other participants), and at least three scans to model within-subject linear change (i.e., individual participant's linear within-subject change). Indeed, four scans or would be required to model non-linear (e.g., quadratic; see King et al., 2018 for a review of longitudinal modeling methods of developmental neuroscience research). It is well-established that many brain regions do not develop linearly (e.g., Vijayakumar 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, although it would likely be quite costly.

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, and sibling and peer relationships, to name a few, that may affect brain development or interact with parenting to affect brain development.

Finally, some consideration should be given to which parent participates in research. The vast majority of this literature has examined effects of maternal rather than paternal parenting, as is common in developmental psychology research (Parent et al., 2017). Until proven otherwise, it may be appropriate to recognize that the existing literature is informative of "mothering," as opposed to "parenting." Nevertheless, paternal behaviors are robustly linked to children's psychopathological outcomes (see Möller et al., 2016 for a meta-analysis), and it will therefore be important to understand convergence and divergence between maternal and paternal influences on offspring brain structure and function.

OTHER CONSIDERATIONS FOR FUTURE STUDY DESIGN

Although noted by Belsky and de Haan (2011), 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 and Jaffee, 2006). There is also substantial evidence that while parenting influences children's behavior and mental health, children's behavior and psychopathological symptoms influence parenting (Kopala-Sibley et al., 2017). These effects and behaviors will be mediated via children's brain development; however, no research has tested this possibility.

Relatedly, there is substantial evidence that parenting behaviors change over time. For example, maternal harsh parenting toward 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.

Another important consideration is whether to diverge from a naturalistic design toward an experimental one. A substantial body of evidence has found 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 and Hagen, 2008). Using these interventions as a tool to examine effects on offspring brain structure and function may be a more cost-effective means of determining associations with causal inference. Yet, solid naturalistic data will be required to determine the optimal periods of development, tasks, and inter-sample interval required for such experimental designs.

CONCLUSION

We reviewed the current literature examining parenting and offspring brain structure or function as well as studies examining offspring brain development over time with a focus on MRI. We identify four thematic design features that have important effects on the hypotheses that can be tested and constrain the possible interpretations of how parenting impacts offspring brain development. As a developmental field, we are primarily interested in change in brain structure and function over time, yet there remains a dearth of repeated measures longitudinal data. This rapidly evolving field is incorporating increasingly rigorous methodologies, and future studies should also consider multiple means of assessing parenting behaviors, including positive parenting behaviors, and testing whether normative parenting and pathological early life adversity lie on a continuum. Studies incorporating these considerations will constitute next generation designs in the field of parenting and offspring brain development.

AUTHOR CONTRIBUTIONS

REFERENCES

Baldwin, J. R., Reuben, A., Newbury, J. B., and Danese, A. (2019). Agreement between prospective and retrospective measures of childhood maltreatment. *JAMA Psychiatry* 76, 584–593. doi: 10.1001/jamapsychiatry.2019.0097

Barbosa, C., Simmons, J. G., Vijayakumar, N., Dudgeon, P., Patton, G. C., Mundy, L. K., et al. (2018). Interaction between parenting styles and adrenarcheal timing associated with affective brain function in late childhood. *J. Am. Acad. Child Adolesc. Psychiatry* 57, 678–686.e4. doi: 10.1016/j.jaac.2018.05.016

Baumrind, D. (1991). "Effective parenting during the early adolescent transition," in *Advances in Family Research Series. Family Transitions*, eds P. A. Cowan and E. M. Hetherington (Mahwah, NJ: Lawrence Erlbaum Associates, Inc), 111–163.

Beckwith, L., Rodning, C., and Cohen, S. (1992). Preterm children at early adolescence and continuity and discontinuity in maternal responsiveness from infancy. *Child Dev.* 63, 1198–1208. doi: 10.1111/j.1467-8624.1992.tb01689.x

Behen, M. E., Muzik, O., Saporta, A. S., Wilson, B. J., Pai, D., Hua, J., et al. (2009). Abnormal fronto-striatal connectivity in children with histories of early deprivation: a diffusion tensor imaging study. *Brain Imaging Behav.* 3, 292–297. doi: 10.1007/s11682-009-9071-6

Belsky, J. (1984). The determinants of parenting: a process model. *Child Dev.* 55, 83–96. doi: 10.2307/1129836

Belsky, J., and de Haan, M. (2011). Annual research review: parenting and children's brain development: the end of the beginning. *J. Child Psychol. Psychiatry* 52, 409–428. doi: 10.1111/j.1469-7610.2010.02281.x

Belsky, J., and Jaffee, S. R. (2006). "The multiple determinants of parenting," in *Developmental Psychopathology: Risk, Disorder, and Adaptation*, eds D. Cicchetti and D. J. Cohen (Hoboken, NJ: John Wiley & Sons, Inc), 38–85. doi: 10.1002/9780470939406.ch2

Bernier, A., Calkins, S. D., and Bell, M. A. (2016). Longitudinal associations between the quality of mother–infant interactions and brain development across infancy. *Child Dev.* 87, 1159–1174. doi: 10.1111/cdev.12518

Bernier, A., Dégeilh, F., Leblanc, É., Daneault, V., Bailey, H. N., and Beauchamp, M. H. (2018). Mother-infant interaction and child brain morphology: a multidimensional approach to maternal sensitivity. *Infancy* 24, 120–138. doi: 10.1111/infa.12270

Boecker, R., Holz, N. E., Buchmann, A. F., Blomeyer, D., Plichta, M. M., Wolf, I., et al. (2014). Impact of early life adversity on reward processing in young adults: EEG- fMRI results from a prospective study over 25 years. *PLoS One* 9:e104185. doi: 10.1371/journal.pone.0104185

Bradley, R. H., and Vandell, D. L. (2007). Child care and the well-being of children. *Arch. Pediatr. Adolesc. Med.* 161, 669–676. doi: 10.1001/archpedi.161.7.669

Brewin, C. R., Andrews, B., and Gotlib, I. H. (1993). Psychopathology and early experience: a reappraisal of retrospective reports. *Psychol. Bull.* 113, 82–98. doi: 10.1037/0033-2909.113.1.82

Brody, G. H., Yu, T., Nusslock, R., Barton, A. W., Miller, G. E., Chen, E., et al. (2019). The protective effects of supportive parenting on the relationship between adolescent poverty and resting-state functional brain connectivity during adulthood. *Psychol. Sci.* 30, 1040–1049. doi: 10.1177/0956797619847989

Burghy, C. A., Stodola, D. E., Ruttle, P. L., Molloy, E. K., Armstrong, J. M., Oler, J. A., et al. (2012). Developmental pathways to amygdala-prefrontal function and internalizing symptoms in adolescence. *Nat. Neurosci.* 15, 1736–1741. doi: 10.1038/nn.3257

Burke, J. D., Pardini, D. A., and Loeber, R. (2008). Reciprocal relationships between parenting behavior and disruptive psychopathology from childhood through adolescence. *J. Abnorm. Child Psychol.* 36, 679–692. doi: 10.1007/s10802-008-9219-7

Butterfield, R., Silk, J., Lee, K. H., Siegle, G., Dahl, R., Forbes, E., et al. (2021). Parents still matter! Parental warmth predicts adolescent brain function and anxiety and depressive symptoms two years later. *Dev. Psychopathol.* 33, 226–239. doi: 10.1017/S0954579419001718

Callaghan, B. L., Dandash, O., Simmons, J. G., Schwartz, O., Byrne, M. L., Sheeber, L., et al. (2017). Amygdala resting connectivity mediates association between maternal aggression and adolescent major depression: a 7-year longitudinal study. *J. Am. Acad. Child Adolesc. Psychiatry* 56, 983–991.e3.

Callaghan, B. L., Gee, D. G., Gabard-Durnam, L., Telzer, E. H., Humphreys, K. L., Goff, B., et al. (2019). Decreased amygdala reactivity to parent cues protects against anxiety following early adversity. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 4, 664–671. doi: 10.1016/j.bpsc.2019.02.001

Chaplin, T. M., Poon, J. A., Thompson, J. C., Hansen, A., Dziura, S. L., Turpyn, C. C., et al. (2019). Sex-differentiated associations among negative parenting, emotion- related brain function, and adolescent substance use and psychopathology symptoms. *Soc. Dev.* 28, 637–656. doi: 10.1111/sode.12364

Choi, J., Jeong, B., Rohan, M. L., Polcari, A. M., and Teicher, M. H. (2009). Preliminary evidence for white matter tract abnormalities in young adults exposed to parental verbal abuse. *Biol. Psychiatry* 65, 227–234. doi: 10.1016/j.biopsych.2008.06.022

Collins, W. A., Maccoby, E. E., Steinberg, L., Hetherington, E. M., and Bornstein, M. H. (2000). Contemporary research on parenting: the case for nature and nurture. *Am. Psychol.* 55, 218–232. doi: 10.1037/0003-066X.55.2.218

Combs-Ronto, L. A., Olson, S. L., Lunkenheimer, E. S., and Sameroff, A. J. (2009). Interactions between maternal parenting and children's early disruptive behavior: bidirectional associations across the transition from preschool to school entry. *J. Abnorm. Child Psychol.* 37, 1151–1163. doi: 10.1007/s10802-009-9332-2

Crone, E. A., and Elzinga, B. M. (2015). Changing brains: how longitudinal functional magnetic resonance imaging studies can inform us about cognitive and social-affective growth trajectories. *Wiley Interdiscip. Rev. Cogn. Sci.* 6, 53–63. doi: 10.1002/wcs.1327

Dallaire, D. H., and Weinraub, M. (2005). The stability of parenting behaviors over the first 6 years of life. *Early Child. Res. Q.* 20, 201–219. doi: 10.1016/j.ecresq.2005.04.008

Dannlowski, U., Stuhrmann, A., Beutelmann, V., Zwanzger, P., Lenzen, T., Grotegerd, D., et al. (2012). Limbic scars: long-term consequences of childhood maltreatment revealed by functional and structural magnetic resonance imaging. *Biol. Psychiatry* 71, 286–293. doi: 10.1016/j.biopsych.2011.10.021

Dégeilh, F., Bernier, A., Leblanc, É., Daneault, V., and Beauchamp, M. H. (2018). Quality of maternal behaviour during infancy predicts functional connectivity between default mode network and salience network 9 years later. *Dev. Cogn. Neurosci.* 34, 53–62. doi: 10.1016/j.dcn.2018.06.003

Dillon, D. G., Holmes, A. J., Birk, J. L., Brooks, N., Lyons-Ruth, K., and Pizzagalli, D. A. (2009). Childhood adversity is associated with left basal ganglia dysfunction during reward anticipation in adulthood. *Biol. Psychiatry* 66, 206–213. doi: 10.1016/j.biopsych.2009.02.019

Eluvathingal, T. J., Chugani, H. T., Behen, M. E., Juhász, C., Muzik, O., Maqbool, M., et al. (2006). Abnormal brain connectivity in children after early severe socioemotional deprivation: a diffusion tensor imaging study. *Pediatrics* 117, 2093–2100. doi: 10.1542/peds.2005-1727

Eshel, N., Daelmans, B., de Mello, M. C., and Martines, J. (2006). Responsive parenting: interventions and outcomes. *Bull. World Health Organ.* 84, 991–998. doi: 10.2471/blt.06.030163

Fareri, D. S., Gabard-Durnam, L., Goff, B., Flannery, J., Gee, D. G., Lumian, D. S., et al. (2017). Altered ventral striatal-medial prefrontal cortex restingstate connectivity mediates adolescent social problems after early institutional care. *Dev. Psychopathol.* 29, 1865–1876. doi: 10.1017/S0954579417001456

Fava, N. M., Trucco, E. M., Martz, M. E., Cope, L. M., Jester, J. M., Zucker, R. A., et al. (2018). Childhood adversity, externalizing behavior, and substance use in adolescence: mediating effects of anterior cingulate cortex activation during inhibitory errors. *Dev. Psychopathol.* 31, 1439–1450. doi: 10.1017/s0954579418001025

Frye, R. E., Malmberg, B., Swank, P., and Smith, K. (2010). Preterm birth and maternal responsiveness during childhood are associated with brain morphology in adolescence. *J. Int. Neuropsychol. Soc.* 16, 784–794. doi: 10.1017/S1355617710000585

Gee, D. G., Gabard-Durnam, L. J., Flannery, J., Goff, B., Humphreys, K. L., Telzer, E. H., et al. (2013). Early developmental emergence of human amygdala-prefrontal connectivity after maternal deprivation. *Proc. Natl. Acad. Sci. U.S.A.* 110, 15638–15643. doi: 10.1073/pnas.1307893110

Goff, B., Gee, D., Telzer, E., Humphreys, K., Gabard-Durnam, L., Flannery, J., et al. (2013). Reduced nucleus accumbens reactivity and adolescent depression following early-life stress. *Neuroscience* 249, 129–138. doi: 10.1016/j.neuroscience.2012.12.010

Govindan, R. M., Behen, M. E., Helder, E., Makki, M. I., and Chugani, H. T. (2010). Altered water diffusivity in cortical association tracts in children with early deprivation identified with tract-based spatial statistics (TBSS). *Cereb. Cortex* 20, 561–569. doi: 10.1093/cercor/bhp122

Graham, A. M., Pfeifer, J. H., Fisher, P. A., Carpenter, S., and Fair, D. A. (2015). Early life stress is associated with default system integrity and emotionality during infancy. *J. Child Psychol. Psychiatry* 56, 1212–1222. doi: 10.1111/jcpp.12409

Grayson, D. S., and Fair, D. A. (2017). Development of large-scale functional networks from birth to adulthood: a guide to the neuroimaging literature. *Neuroimage* 160, 15–31. doi: 10.1016/j.neuroimage.2017.01.079

Guyer, A. E., Jarcho, J. M., Pérez-Edgar, K., Degnan, K. A., Pine, D. S., Fox, N. A., et al. (2015). Temperament and parenting styles in early childhood differentially influence neural response to peer evaluation in adolescence. *J. Abnorm. Child Psychol.* 43, 863–874. doi: 10.1007/s10802-015-9973-2

Hanson, J. L., Adluru, N., Chung, M. K., Alexander, A. L., Davidson, R. J., and Pollak, S. D. (2013). Early neglect is associated with alterations in white matter integrity and cognitive functioning. *Child Dev.* 84, 1566–1578. doi: 10.1111/cdev.12069

Hanson, J. L., Chung, M. K., Avants, B. B., Rudolph, K. D., Shirtcliff, E. A., Gee, J. C., et al. (2012). Structural variations in prefrontal cortex mediate the relationship between early childhood stress and spatial working memory. *J. Neurosci.* 32, 7917–7925. doi: 10.1523/jneurosci.0307-12.2012

Hanson, J. L., Hariri, A. R., and Williamson, D. E. (2015a). Blunted ventral striatum development in adolescence reflects emotional neglect and predicts depressive symptoms. *Biol. Psychiatry* 78, 598–605. doi: 10.1016/j.biopsych.2015.05.010

Hanson, J. L., Nacewicz, B. M., Sutterer, M. J., Cayo, A. A., Schaefer, S. M., Rudolph, K. D., et al. (2015b). Behavioral problems after early life stress: contributions of the hippocampus and Amygdala. *Biol. Psychiatry* 77, 314–323. doi: 10.1016/j.biopsych.2014.04.020

Hardt, J., and Rutter, M. (2004). Validity of adult retrospective reports of adverse childhood experiences: review of the evidence. *J. Child Psychol. Psychiatry* 45, 260–273. doi: 10.1111/j.1469-7610.2004.00218.x

Hawes, D. J., Dadds, M. R., Frost, A. D. J., and Hasking, P. A. (2011). Do childhood callous- unemotional traits drive change in parenting practices? *J. Clin. Child Adolesc. Psychol.* 40, 507–518. doi: 10.1080/15374416.2011.581624

Heim, C. M., Mayberg, H. S., Mletzko, T., Nemeroff, C. B., and Pruessner, J. C. (2013). Decreased cortical representation of genital somatosensory field after childhood sexual abuse. *Am. J. Psychiatry* 170, 616–623. doi: 10.1176/appi.ajp.2013.12070950

Henry, B., Moffitt, T. E., Caspi, A., Langley, J., and Silva, P. A. (1994). On the "Remembrance of Things Past": a longitudinal evaluation of the retrospective method. *Psychol. Assess.* 6, 92–101. doi: 10.1037/1040-3590.6.2.92

Hensch, T. K. (2004). Critical period regulation. *Annu. Rev. Neurosci.* 27, 549–579. doi: 10.1146/annurev.neuro.27.070203.144327

Herringa, R. J., Birn, R. M., Ruttle, P. L., Burghy, C. A., Stodola, D. E., Davidson, R. J., et al. (2013). Childhood maltreatment is associated with altered fear circuitry and increased internalizing symptoms by late adolescence. *Proc. Natl. Acad. Sci. U.S.A.* 110, 19119–19124. doi: 10.1073/pnas.1310766110

Herringa, R. J., Burghy, C. A., Stodola, D. E., Fox, M. E., Davidson, R. J., and Essex, M. J. (2016). Enhanced prefrontal-amygdala connectivity following childhood adversity as a protective mechanism against internalizing in adolescence. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 1, 326–334. doi: 10.1016/j.bpsc.2016.03.003

Holmes, C. J., Barton, A. W., Mackillop, J., Galván, A., Owens, M. M., Mccormick, M. J., et al. (2018). Parenting and salience network connectivity among African Americans: a protective Pathway for health-risk behaviors. *Biol. Psychiatry* 84, 365–371. doi: 10.1016/j.biopsych.2018.03.003

Huang, H., Gundapuneedi, T., and Rao, U. (2012). White matter disruptions in adolescents exposed to childhood maltreatment and vulnerability to psychopathology. *Neuropsychopharmacology* 37, 2693–2701. doi: 10.1038/npp.2012.133

Jiang, N., Xu, J., Li, X., Wang, Y., Zhuang, L., and Qin, S. (2021). Negative parenting affects adolescent internalizing symptoms through alterations in amygdala-prefrontal circuitry: a longitudinal twin study. *Biol. Psychiatry* 89, 560–569. doi: 10.1016/j.biopsych.2020.08.002

Kazdin, A. E. (2005). "Child, parent, and family-based treatment of aggressive and antisocial child behavior," in *Psychosocial Treatments for Child and Adolescent Disorders: Empirically Based Strategies for Clinical Practice*, 2nd Edn, eds E. D. Hibbs and P. S. Jensen (Washington DC: American Psychological Association), 445–476.

Kim, H. K., Pears, K. C., Fisher, P. A., Connelly, C. D., and Landsverk, J. A. (2010). Trajectories of maternal harsh parenting in the first 3 years of life. *Child Abuse Negl.* 34, 897–906. doi: 10.1016/j.chiabu.2010.06.002

King, K. M., Littlefield, A. K., McCabe, C. J., Mills, K. L., Flournoy, J., and Chassin, L. (2018). Longitudinal modeling in developmental neuroimaging research: common challenges, and solutions from developmental psychology. *Dev. Cogn. Neurosci.* 33, 54–72.

Kok, R., Thijssen, S., Bakermans-Kranenburg, M. J., Jaddoe, V. W., Verhulst, F. C., White, T., et al. (2015). Normal variation in early parental sensitivity predicts child structural brain development. *J. Am. Acad. Child Adolesc. Psychiatry* 54, 824–831. doi: 10.1016/j.jaac.2015.07.009

Kopala-Sibley, D. C., Cyr, M., Finsaas, M. C., Orawe, J., Huang, A., Tottenham, N., et al. (2020). Early childhood parenting predicts late childhood brain functional connectivity during emotion perception and reward processing. *Child Dev.* 91, 110–128. doi: 10.1111/cdev.13126

Kopala-Sibley, D. C., Jelinek, C., Kessel, E., Frost, A., Allmann, A. E., and Klein, D. N. (2017). Parental depressive history, parenting styles, and child psychopathology over six years: the contribution of each parent's depressive history to the other's parenting styles. *Dev. Psychopathol.* 29, 1469–1482. doi: 10.1017/S0954579417000396

Kujawa, A., Klein, D. N., Pegg, S., and Weinberg, A. (2020). Developmental trajectories to reduced activation of positive valence systems: a review of biological and environmental contributions. *Dev. Cogn. Neurosci.* 43:100791. doi: 10.1016/j.dcn.2020.100791

Landry, S. H., Smith, K. E., Swank, P. R., and Guttentag, C. (2008). A responsive parenting intervention: the optimal timing across early childhood for impacting maternal behaviors and child outcomes. *Dev. Psychol.* 44, 1335–1353. doi: 10.1037/a0013030

Lee, K. H., Siegle, G. J., Dahl, R. E., Hooley, J. M., and Silk, J. S. (2014). Neural responses to maternal criticism in healthy youth. *Soc. Cogn. Affect. Neurosci.* 10, 902–912. doi: 10.1093/scan/nsu133

Lee, S. W., Yoo, J. H., Kim, K. W., Kim, D., Park, H., Choi, J., et al. (2018). Hippocampal subfields volume reduction in high schoolers with previous verbal abuse experiences. *Clin. Psychopharmacol. Neurosci.* 16, 46–56. doi: 10.9758/cpn.2018.16.1.46

Lee, S. W., Yoo, J. H., Kim, K. W., Lee, J., Kim, D., Park, H., et al. (2016). Corrigendum to "Aberrant function of frontoamygdala circuits in adolescents with previous verbal abuse experiences" [Neuropsychologia, 79 (2015) 76–85]. *Neuropsychologia* 84:294. doi: 10.1016/j.neuropsychologia.2016.01.013

Lipscomb, S. T., Leve, L. D., Harold, G. T., Neiderhiser, J. M., Shaw, D. S., Ge, X., et al. (2011). Trajectories of parenting and child negative emotionality during infancy and toddlerhood: a longitudinal analysis. *Child Dev.* 82, 1661–1675. doi: 10.1111/j.1467-8624.2011.01639.x

Luby, J., Belden, A., Botteron, K., Marrus, N., Harms, M. P., Babb, C., et al. (2013). The effects of poverty on childhood brain development: the mediating effect of caregiving and stressful life events. *JAMA Pediatrics* 167, 1135–1142. doi: 10.1001/jamapediatrics.2013.3139

Luby, J. L., Barch, D. M., Belden, A., Gaffrey, M. S., Tillman, R., Babb, C., et al. (2012). Maternal support in early childhood predicts larger hippocampal volumes at school age. *Proc. Natl. Acad. Sci. U.S.A.* 109, 2854–2859. doi: 10.1073/pnas.1118003109

Luby, J. L., Tillman, R., and Barch, D. M. (2019). Association of timing of adverse childhood experiences and caregiver support with regionally specific brain development in adolescents. *JAMA Netw. Open* 2:e1911426. doi: 10.1001/jamanetworkopen.2019.11426

Lupien, S. J., Parent, S., Evans, A. C., Tremblay, R. E., Zelazo, P. D., Corbo, V., et al. (2011). Larger amygdala but no change in hippocampal volume in 10-year-old children exposed to maternal depressive symptomatology since birth. *Proc. Natl. Acad. Sci. U.S.A.* 108, 14324–14329. doi: 10.1073/pnas.1105371108

Maupin, A. N., Hayes, N. J., Mayes, L. C., and Rutherford, H. J. (2015). The application of electroencephalography to investigate the neural bases of parenting: a review. *Parent. Sci. Pract.* 15, 9–23. doi: 10.1080/15295192.2015.992735

McCrory, E. J., Brito, S. A., Kelly, P. A., Bird, G., Sebastian, C. L., Mechelli, A., et al. (2013). Amygdala activation in maltreated children during pre-attentive emotional processing. *Br. J. Psychiatry* 202, 269–276. doi: 10.1192/bjp.bp.112.116624

McCrory, E. J., Brito, S. A., Sebastian, C. L., Mechelli, A., Bird, G., Kelly, P. A., et al. (2011). Heightened neural reactivity to threat in child victims of family violence. *Curr. Biol.* 21, R947–R948. doi: 10.1016/j.cub.2011.10.015

McLaughlin, K. A., Sheridan, M. A., Winter, W., Fox, N. A., Zeanah, C. H., and Nelson, C. A. (2014). Widespread reductions in cortical thickness following severe early-life deprivation: a neurodevelopmental pathway to attention-deficit/hyperactivity disorder. *Biol. Psychiatry* 76, 629–638. doi: 10.1016/j.biopsych.2013.08.016

McLeod, B. D., Wood, J. J., and Weisz, J. R. (2007a). Examining the association between parenting and childhood anxiety: a meta-analysis. *Clin. Psychol. Rev.* 27, 155–172. doi: 10.1016/j.cpr.2006.09.002

McLeod, B. D., Weisz, J. R., and Wood, J. J. (2007b). Examining the association between parenting and childhood depression: a meta-analysis. *Clin. Psychol. Rev.* 27, 986–1003. doi: 10.1016/j.cpr.2007.03.001

Mehta, M. A., Golembo, N. I., Nosarti, C., Colvert, E., Mota, A., Williams, S. C., et al. (2009). Amygdala, hippocampal and corpus callosum size following severe early institutional deprivation: the English and Romanian adoptees study pilot. *J. Child Psychol. Psychiatry* 50, 943–951. doi: 10.1111/j.1469-7610.2009.02084.x

Merz, E. C., Maskus, E. A., Melvin, S. A., He, X., and Noble, K. G. (2019). Parental punitive discipline and children's depressive symptoms: associations with striatal volume. *Dev. Psychobiol.* 61, 953–961. doi: 10.1002/dev.21859

Meyer, A., Proudfit, G. H., Bufferd, S. J., Kujawa, A. J., Laptook, R. S., Torpey, D. C., et al. (2015). Self-reported and observed punitive parenting prospectively predicts increased error-related brain activity in six-year old children. *J. Abnorm. Child Psychol.* 43, 821–829. doi: 10.1007/s10802-014-9918-1

Möller, E. L., Nikolić, M., Majdandžić, M., and Bögels, S. M. (2016). Associations between maternal and paternal parenting behaviors, anxiety and its precursors in early childhood: a meta-analysis. *Clin. Psychol. Rev.* 45, 17–33. doi: 10.1016/j.cpr.2016.03.002

Morgan, J. K., Shaw, D. S., and Forbes, E. E. (2014). Maternal depression and warmth during childhood predict age 20 neural response to reward. *J. Am. Acad. Child Adolesc. Psychiatry* 53, 108–117. doi: 10.1016/j.jaac.2013.10.003

Mueller, S. C., Maheu, F. S., Dozier, M., Peloso, E., Mandell, D., Leibenluft, E., et al. (2010). Early-life stress is associated with impairment in cognitive control in adolescence: an fMRI study. *Neuropsychologia* 48, 3037–3044. doi: 10.1016/j.neuropsychologia.2010.06.013

Ogden, T., and Hagen, K. A. (2008). Treatment effectiveness of parent management training in Norway: a randomized controlled trial of children with conduct problems. *J. Consult. Clin. Psychol.* 76, 607–621. doi: 10.1037/0022-006X.76.4.607

Ohashi, K., Anderson, C. M., Bolger, E. A., Khan, A., Mcgreenery, C. E., and Teicher, M. H. (2017). Childhood maltreatment is associated with alteration in global network fiber-tract architecture independent of history of depression and anxiety. *Neuroimage* 150, 50–59. doi: 10.1016/j.neuroimage.2017.02.037

Pagliaccio, D., Luby, J. L., Bogdan, R., Agrawal, A., Gaffrey, M. S., Belden, A. C., et al. (2015). Amygdala functional connectivity, HPA axis genetic variation, and life stress in children and relations to anxiety and emotion regulation. *J. Abnorm. Psychol.* 124, 817–833. doi: 10.1037/abn0000094

Pardini, D. A., Fite, P. J., and Burke, J. D. (2008). Bidirectional associations between parenting practices and conduct problems in boys from childhood to adolescence: the moderating effect of age and African-American ethnicity. *J. Abnorm. Child Psychol.* 36, 647–662. doi: 10.1007/s10802-007-9162-z

Parent, J., Forehand, R., Pomerantz, H., Peisch, V., and Seehuus, M. (2017). Father participation in child psychopathology research. *J. Abnormal Child Psychol.* 45, 1259–1270.

Philip, N. S., Kuras, Y. I., Valentine, T. R., Sweet, L. H., Tyrka, A. R., Price, L. H., et al. (2013a). Regional homogeneity and resting state functional connectivity: associations with exposure to early life stress. *Psychiatry Res.* 214, 247–253. doi: 10.1016/j.pscychresns.2013.07.013

Philip, N. S., Sweet, L. H., Tyrka, A. R., Price, L. H., Carpenter, L. L., Kuras, Y. I., et al. (2013b). Early life stress is associated with greater default network deactivation during working memory in healthy controls: a preliminary report. *Brain Imaging Behav.* 7, 204–212. doi: 10.1007/s11682-012-9216-x

Pozzi, E., Bousman, C. A., Simmons, J. G., Vijayakumar, N., Schwartz, O., Seal, M., et al. (2019). Interaction between hypothalamic-pituitary- adrenal axis genetic variation and maternal behavior in the prediction of amygdala connectivity in children. *Neuroimage* 197, 493–501. doi: 10.1016/j.neuroimage.2019.05.013

Pozzi, E., Simmons, J. G., Bousman, C. A., Vijayakumar, N., Bray, K. O., Dandash, O., et al. (2020). The influence of maternal parenting style on the neural correlates of emotion processing in children. *J. Am. Acad. Child Adolesc. Psychiatry* 59, 272–282. doi: 10.1016/j.jaac.2019.01.018

Pozzi, E., Vijayakumar, N., Byrne, M. L., Bray, K. O., Seal, M., Richmond, S., et al. (2021). Maternal parenting behavior and functional connectivity development in children: a longitudinal fMRI study. *Dev. cogn. Neurosci.* 48:100946

Rao, H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Korczykowski, M., Avants, B. B., et al. (2010). Early parental care is important for hippocampal maturation: evidence from brain morphology in humans. *Neuroimage* 49, 1144–1150. doi: 10.1016/j.neuroimage.2009.07.003

Richmond, S., Beare, R., Johnson, K. A., Allen, N. B., Seal, M. L., and Whittle, S. (2019). Structural covariance networks in children and their associations with maternal behaviors. *Neuroimage* 202:115965. doi: 10.1016/j.neuroimage.2019.06.043

Romund, L., Raufelder, D., Flemming, E., Lorenz, R. C., Pelz, P., Gleich, T., et al. (2016). Maternal parenting behavior and emotion processing in adolescents— An fMRI study. *Biol. Psychol.* 120, 120–125. doi: 10.1016/j.biopsycho.2016.09.003

Rose, J., Roman, N., Mwaba, K., and Ismail, K. (2017). The relationship between parenting and internalizing behaviours of children: a systematic review. *Early Child Dev. Care* 188, 1468–1486. doi: 10.1080/03004430.2016.1269762

Roth, M. C., Humphreys, K. L., King, L. S., and Gotlib, I. H. (2018). Self-reported neglect, amygdala volume, and symptoms of anxiety in adolescent boys. *Child Abuse Negl.* 80, 80–89. doi: 10.1016/j.chiabu.2018.03.016

Schneider, S., Brassen, S., Bromberg, U., Banaschewski, T., Conrod, P., Flor, H., et al. (2012). Maternal interpersonal affiliation is associated with adolescents' brain structure and reward processing. *Transl. Psychiatry* 2:e182. doi: 10.1038/tp.2012.113

Sessa, F. M., Avenevoli, S., Steinberg, L., and Morris, A. S. (2001). Correspondence among informants on parenting: preschool children, mothers, and observers. *J. Fam. Psychol.* 15, 53–68. doi: 10.1037/0893-3200.15.1.53

Sheikh, H. I., Joanisse, M. F., Mackrell, S. M., Kryski, K. R., Smith, H. J., Singh, S. M., et al. (2014). Links between white matter microstructure and cortisol reactivity to stress in early childhood: evidence for moderation by parenting. *Neuroimage Clin.* 6, 77–85. doi: 10.1016/j.nicl.2014.08.013

Sheridan, M. A., Fox, N. A., Zeanah, C. H., Mclaughlin, K. A., and Nelson, C. A. (2012). Variation in neural development as a result of exposure to institutionalization early in childhood. *Proc. Natl. Acad. Sci. U.S.A.* 109, 12927–12932. doi: 10.1073/pnas.1200041109

Soe, N. N., Wen, D. J., Poh, J. S., Chong, Y., Broekman, B. F., Chen, H., et al. (2016). Pre- and Post-natal maternal depressive symptoms in relation with infant frontal function, connectivity, and behaviors. *PLoS One* 11:e0152991. doi: 10.1371/journal.pone.0152991

Steen, R. G., Hamer, R. M., and Lieberman, J. A. (2007). Measuring brain volume by MR imaging: impact of measurement precision and natural variation on sample size requirements. *Am. J. Neuroradiol.* 28, 1119–1125. doi: 10.3174/ajnr.a0537

Stein, M. B., Koverola, C., Hanna, C., Torchia, M. G., and Mcclarty, B. (1997). Hippocampal volume in women victimized by childhood sexual abuse. *Psychol. Med.* 27, 951–959. doi: 10.1017/s0033291797005242

Suffren, S., La Buissonnière-Ariza, V., Tucholka, A., Nassim, M., Séguin, J. R., Boivin, M., et al. (2021). Prefrontal cortex and amygdala anatomy in youth with persistent levels of harsh parenting practices and subclinical anxiety symptoms over time during childhood. *Dev. Psychopathol.* 1–12.

Tamnes, C. K., Roalf, D. R., Goddings, A. L., and Lebel, C. (2018). Diffusion MRI of white matter microstructure development in childhood and adolescence: methods, challenges and progress. *Dev. Cogn. Neurosci.* 33, 161–175. doi: 10.1016/j.dcn.2017.12.002

Tan, P. Z., Oppenheimer, C. W., Ladouceur, C. D., Butterfield, R. D., and Silk, J. S. (2020). A review of associations between parental emotion socialization behaviors and the neural substrates of emotional reactivity and regulation in youth. *Dev. Psychol.* 56, 516–527. doi: 10.1037/dev0000893

Taylor, S. E., Eisenberger, N. I., Saxbe, D., Lehman, B. J., and Lieberman, M. D. (2006). Neural responses to emotional stimuli are associated with childhood family stress. *Biol. Psychiatry* 60, 296–301. doi: 10.1016/j.biopsych.2005.09.027

Teicher, M. H., Anderson, C. M., Ohashi, K., Khan, A., McGreenery, C. E., Bolger, E. A., et al. (2018). Differential effects of childhood neglect and abuse during sensitive exposure periods on male and female hippocampus. *Neuroimage* 169, 443–452. doi: 10.1016/j.neuroimage.2017.12.055

Teicher, M. H., Dumont, N. L., Ito, Y., Vaituzis, C., Giedd, J. N., and Andersen, S. L. (2004). Childhood neglect is associated with reduced corpus callosum area. *Biol. Psychiatry* 56, 80–85. doi: 10.1016/j.biopsych.2004.03.016

Thijssen, S., Muetzel, R. L., Bakermans-Kranenburg, M. J., Jaddoe, V. W., Tiemeier, H., Verhulst, F. C., et al. (2017). Insensitive parenting may accelerate the development of the amygdala–medial prefrontal cortex circuit. *Dev. Psychopathol.* 29, 505–518. doi: 10.1017/s0954579417000141

Thomason, M. E., Marusak, H. A., Tocco, M. A., Vila, A. M., McGarragle, O., and Rosenberg, D. R. (2015). Altered amygdala connectivity in urban youth exposed to trauma. *Soc. Cogn. Affect. Neurosci.* 10, 1460–1468. doi: 10.1093/scan/nsv030

Tomoda, A., Sheu, Y., Rabi, K., Suzuki, H., Navalta, C. P., Polcari, A., et al. (2011). Exposure to parental verbal abuse is associated with increased gray matter volume in superior temporal gyrus. *Neuroimage* 54, 280–286. doi: 10.1016/j.neuroimage.2010.05.027

Tomoda, A., Suzuki, H., Rabi, K., Sheu, Y., Polcari, A., and Teicher, M. H. (2009). Reduced prefrontal cortical gray matter volume in young adults exposed to

harsh corporal punishment. *Neuroimage* 47, 66–71. doi: 10.1016/j.neuroimage. 2009.03.005

Tottenham, N., Hare, T., Millner, A., Gilhooly, T., Zevin, J., and Casey, B. (2011). Elevated amygdala response to faces following early deprivation. *Dev. Sci.* 14, 190–204. doi: 10.1111/j.1467-7687.2010.00971.x

Tottenham, N., Hare, T. A., Quinn, B. T., Mccarry, T. W., Nurse, M., Gilhooly, T., et al. (2010). Prolonged institutional rearing is associated with atypically large amygdala volume and difficulties in emotion regulation. *Dev. Sci.* 13, 46–61. doi: 10.1111/j.1467-7687.2009.00852.x

Tyborowska, A., Volman, I., Niermann, H. C., Pouwels, J. L., Smeekens, S., Cillessen, A. H., et al. (2018). Early-life and pubertal stress differentially modulate grey matter development in human adolescents. *Sci. Rep.* 8:9201. doi: 10.1038/s41598-018-27439-5

Van der Werff, S. J. A., Pannekoek, J. N., Veer, I. M., van Tol, M. J., Aleman, A., Veltman, D. J., et al. (2013). Resting-state functional connectivity in adults with childhood emotional maltreatment. *Psychol. Med.* 43, 1825–1836. doi: 10.1017/S0033291712002942

Vidal-Ribas, P., Benson, B., Vitale, A. D., Keren, H., Harrewijn, A., Fox, N. A., et al. (2019). Bidirectional associations between stress and reward processing in children and adolescents: a longitudinal neuroimaging study. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 4, 893–901. doi: 10.1016/j.bpsc.2019.05.012

Vijayakumar, N., Allen, N. B., Youssef, G., Dennison, M., Yücel, M., Simmons, J. G., et al. (2016). Brain development during adolescence: a mixed-longitudinal investigation of cortical thickness, surface area, and volume. *Hum. Brain Mapp.* 37, 2027–2038. doi: 10.1002/hbm.23154

Vijayakumar, N., Mills, K. L., Alexander-Bloch, A., Tamnes, C. K., and Whittle, S. (2018). Structural brain development: a review of methodological approaches and best practices. *Dev. Cogn. Neurosci.* 33, 129–148. doi: 10.1016/j.dcn.2017. 11.008

Waite, P., Whittington, L., and Creswell, C. (2014). Parent-child interactions and adolescent anxiety: a systematic review. *J. Exp. Psychopathol.* 1, 51–76. doi: 10.5127/pr.033213

Walsh, N. D., Dalgleish, T., Lombardo, M. V., Dunn, V. J., Harmelen, A. V., Ban, M., et al. (2014). General and specific effects of early-life psychosocial adversities on adolescent grey matter volume. *Neuroimage Clin.* 4, 308–318. doi: 10.1016/j.nicl.2014.01.001

Wang, M. T., Dishion, T. J., Stormshak, E. A., and Willett, J. B. (2011). Trajectories of family management practices and early adolescent behavioral outcomes. *Dev. Psychol.* 47, 1324–1341. doi: 10.1037/a0024026

Wang, Q., Zhang, H., Wee, C., Lee, A., Poh, J. S., Chong, Y., et al. (2019). Maternal sensitivity predicts anterior hippocampal functional networks in early childhood. *Brain Struct. Funct.* 224, 1885–1895. doi: 10.1007/s00429-019-01882-0

Whittle, S., Dennison, M., Vijayakumar, N., Simmons, J. G., Yücel, M., Lubman, D. I., et al. (2013a). Childhood maltreatment and psychopathology affect brain development during adolescence. *J. Am. Acad. Child Adolesc. Psychiatry* 52, 824–832.

Whittle, S., Julian, S., Meg, D., Nandita, V., Orli, S., Marie, Y., et al. (2013b). Positive parenting predicts the development of adolescent neural reward circuitry: a longitudinal study. *Dev. Cogn. Neurosci.* 8, 7–17. doi: 10.3389/conf.fnhum.2013. 212.00074

Whittle, S., Simmons, J. G., Dennison, M., Vijayakumar, N., Schwartz, O., Yap, M. B. H., et al. (2014). Positive parenting predicts the development of adolescent brain structure: a longitudinal study. *Dev. Cogn. Neurosci.* 8, 7–17. doi: 10.1016/j.dcn.2013.10.006

Whittle, S., Vijayakumar, N., Dennison, M., Schwartz, O., Simmons, J. G., Sheeber, L., et al. (2016). Observed measures of negative parenting predict brain development during adolescence. *PLoS One* 11:e0147774. doi: 10.1371/journal. pone.0147774

Whittle, S., Vijayakumar, N., Simmons, J. G., Dennison, M., Schwartz, O., Pantelis, C., et al. (2017). Role of positive parenting in the association between

neighborhood social disadvantage and brain development across adolescence. *JAMA Psychiatry* 74, 824–832. doi: 10.1016/j.biopsych.2004.03.016

Whittle, S., Yap, M. B., Sheeber, L., Dudgeon, P., Yücel, M., Pantelis, C., et al. (2011). Hippocampal volume and sensitivity to maternal aggressive behavior: a prospective study of adolescent depressive symptoms. *Dev. Psychopathol.* 23, 115–129. doi: 10.1017/s0954579410000684

Whittle, S., Yap, M. B., Yucel, M., Fornito, A., Simmons, J. G., Barrett, A., et al. (2008). Prefrontal and amygdala volumes are related to adolescents affective behaviors during parent-adolescent interactions. *Proc. Natl. Acad. Sci. U.S.A.* 105, 3652–3657. doi: 10.1073/pnas.0709815105

Whittle, S., Yap, M. B., Yucel, M., Sheeber, L., Simmons, G., Pantelis, C., et al. (2009). Maternal responses to adolescent positive affect are associated with adolescents' reward neuroanatomy. *Soc. Cogn. Affect. Neurosci.* 4, 247–256. doi: 10.1093/scan/nsp012

Wildeman, C., Emanuel, N., Leventhal, J. M., Putnam-Hornstein, E., Waldfogel, J., and Lee, H. (2014). The prevalence of confirmed maltreatment among US children, 2004 to 2011. *JAMA Pediatr.* 168, 706–713. doi: 10.1001/ jamapediatrics.2014.410

Williamson, P. C., Osuch, E. A., and Lanius, R. A. (2009). Alterations in default network connectivity in posttraumatic stress disorder related to early-life trauma. *J. Psychiatry Neurosci.* 34, 187–194. doi: 10.1002/9780470713570.ch10

Wolf, R. C., and Herringa, R. J. (2016). Prefrontal–amygdala dysregulation to threat in pediatric posttraumatic stress disorder. *Neuropsychopharmacology* 41, 822–831. doi: 10.1038/npp.2015.209

Yap, M. B., Whittle, S., Yücel, M., Sheeber, L., Pantelis, C., Simmons, J. G., et al. (2008). Interaction of parenting experiences and brain structure in the prediction of depressive symptoms in adolescents. *Arch. Gen. Psychiatry* 65, 1377–1385. doi: 10.1001/archpsyc.65.12.1377

Yap, M. B. H., Morgan, A. J., Cairns, K., Jorm, A. F., Hetrick, S. E., and Merry, S. (2016). Parents in prevention: a meta-analysis of randomized controlled trials of parenting interventions to prevent internalizing problems in children from birth to age 18. *Clin. Psychol. Rev.* 50, 138–158. doi: 10.1016/j.cpr.2016.10.003

Yarrow, M. R., Campbell, J. D., and Burton, R. V. (1970). Recollections of childhood a study of the retrospective method. *Monogr. Soc. Res. Child Dev.* 35, 1–83. doi: 10.2307/1165649

Zaslow, M. J., Weinfeld, N. S., Gallagher, M., Hair, E. C., Ogawa, J. R., Egeland, B., et al. (2006). Longitudinal prediction of child outcomes from differing measures of parenting in a low-income sample. *Dev. Psychol.* 42, 27–37. doi: 10.1037/0012-1649.42.1.27

Zhu, J., Lowen, S. B., Anderson, C. M., Ohashi, K., Khan, A., and Teicher, M. H. (2019). Association of prepubertal and postpubertal exposure to childhood maltreatment with adult amygdala function. *JAMA Psychiatry* 76, 843–853. doi: 10.1001/jamapsychiatry.2019.0931