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Review article

Parental influences on neural mechanisms underlying emotion regulation

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ABSTRACT

Emotional intelligence allows for the recognition and regulation of emotions in the self and others, making it critical for healthy social and emotional development. Research has shown that the parent-child relationship and family environment are influential in the development of emotion regulation, one key component of emotional intelligence. However, the neurobiological processes underlying this relationship have yet to be fully explored. This review examines perspectives from several disciplines to further understand the influence of parent-child interactions on the neurocircuitry shaping emotion regulation. Our proposed model demonstrates how parent-child interactions and parents' emotion regulation neurocircuitry may influence the development of children's own emotion regulation neurocircuitry, with a specific focus on associations among prefrontal regions, the anterior insula, and the amygdala.

1. Introduction

Recent research suggests that interactions with caregivers influence brain development, structure, and function [8,3,64]. The purpose of this brief review is to bring together perspectives from neuroscience, developmental psychology, family science, and clinical psychology to focus on potential neural systems involved in emotion regulation (ER) and the role of parental influence on these neural systems across development. ER is a core component of emotional intelligence and encompasses skills necessary for the awareness and appropriate modulation of one's own emotions, as well as the ability to recognize and discern the emotions of others [53]. ER skills allow an individual to manage emotions in order to promote adaptive behavior critical to healthy social and emotional development [42]. The development of ER in childhood and adolescence is especially essential, as effective ER skills are associated with healthy future relationships [43]. Moreover, ER abilities are related to behavioral and mental health outcomes including academic achievement, prosocial behavior, social skills, and internalizing and externalizing behaviors [11]. An understanding of the neurocircuitry underlying the development of ER that occurs in relational contexts is of particular importance for the development of brain-based interventions to improve ER in children and adolescents.

Parents typically play a vital role in the development of children's ER [42]. ER is both a dynamic and dyadic process due to changes over time within the context of the parent-child relationship [9,17]. Morris et al. [42] proposed a three-part model through which the family influences ER in the developing child [44]. First, the model suggests that children learn ER through modeling and observation of parents', siblings', and others' emotions and ER. Second, parents are thought to guide children in their development of ER through socialization efforts and specific parenting behaviors in response to emotions. These behaviors help children learn, identify, and manage emotions with the support and guidance of the parent [42]. Third, the emotional climate of the family, whether warm and supportive or controlling and harsh, is proposed to greatly influence the development of ER. Children typically develop healthy ER strategies in families that are supportive and have consistent rules, whereas children can become hyperreactive or hyporeactive to emotional stimuli in families marked by inconsistency and hostility [42]. In subsequent sections of this review, we align this three-part theory with relevant neuroscience research to provide an enhanced understanding of the neurobiological development of ER. Then, we present a new model of dyadic ER neurocircuitry to guide future research and its application for potential brain-based interventions.

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2. Modeling and observation

In regard to modeling, findings from previous studies suggest that infants and toddlers recognize and imitate facial expressions when interacting with parents, caregivers, and peers [67,49]. For example, infants of mothers who are emotionally withdrawn, often due to depression, tend to show fewer facial expressions and less emotional responsiveness during social interactions [37,14]. Additionally, children may look to a parent to seek information on how to respond during an emotion-eliciting situation, a behavior that developmental psychologists call social referencing [42,55,21]. These reciprocal parent-child interactions, referred to as social synchrony, help children understand emotional situations and learn to regulate their own emotions [12]. Research indicates that modeling and observation play a significant role in ER during middle childhood and adolescence as well [42,7,16,41].

Observational learning and modeling may be supported by cortical networks with similar properties to the mirror neuron system that has been extensively studied in nonhuman primates. Similar to nonhuman primates, the human motor cortex can activate in response to observing an action performed by another individual [50]. Another potential mirroring pattern in humans is activation in the anterior insula, anterior cingulate cortex (ACC), and amygdala as a sign of empathy and emotional contagion [60]. This activity in humans may provide a neurophysiological mechanism for a variety of important social behaviors, from imitation to empathy, as well as affecting social cognition [28]. Further research is needed to determine the extent to which different brain regions implicated as similar to the mirror neuron system may allow for human observational learning and modeling by means of social imitation and theory of mind [27].

3. Emotion socialization

Emotion socialization begins in early childhood with parents teaching their children how to manage their emotions through the use of emotion labeling, discussion, and the encouragement of specific regulation strategies [42,15]. This dyadic interaction can be influential in laying the foundation for future social interactions. For example, a study aimed at improving emotion socialization found children's knowledge of their emotions increased when parents used greater emotion socialization strategies such as emotion coaching and empathy [23]. Among these same children, a significant decrease in problem behaviors was also found [23]. Additionally, Perlman and colleagues [47] found preschool-aged children whose parents encouraged emotional expression showed greater knowledge of their own emotions and emotional situations. Similar findings have been demonstrated in studies of parent-adolescent emotion socialization. High levels of positive parent emotion socialization and emotion coaching were associated with higher levels of adolescent ER [10,26], suggesting direct links between parents' supportive responses to emotions and youth's ER.

We argue that these emotion-related parenting practices are closely linked with emotion regulatory brain networks, primarily regions in the prefrontal cortex (PFC; dorsolateral PFC dlPFC], medial PFC [mPFC], and ventrolateral PFC [vlPFC]) and ACC. Parental behaviors that encourage children to regulate emotions likely influence, and are influenced by, prefrontal inhibitory circuitry in both parents and children. For example, parents who exhibit greater activation in regions including the dlPFC and vlPFC while completing an emotional faces task tend to have adolescent children with better emotional competence [58]. Moreover, in a study of mothers' neural responses to hearing their own baby's cry, sensitive mothers (those showing behavioral attunement and responsivity) exhibited hyperactivation in the PFC, while intrusive mothers (those showing more forceful physical guidance) demonstrated increased activity in empathy-related areas such as the insula [45]. These findings suggest that mothers with enhanced ER skills may better respond to their child's needs, whereas mothers who do not possess these skills may be more reactive and less equipped to problem solve. Finally, children who experience harsh corporal punishment from caregivers have reduced grey matter volumes in the mPFC, dlPFC, and ACC in adulthood [59]. Although correlational, this evidence suggests that harsh parenting practices may affect the development of these emotion regulatory regions. In sum, the PFC and ACC appear to be implicated in emotion-related parenting practices as well as in a child's development of ER abilities.

4. Emotional climate of the family

In infancy and early childhood, the emotional climate of the family is often reflected in the development of a secure or insecure attachment style [42]. Children tend to form secure attachments to parents who are responsive and nurturing, which leads to less emotional reactivity upon short separations from their parent. Conversely, children may form insecure attachments to parents that are less responsive and inconsistent, leading to greater emotional reactivity during periods of separation and upon reunion [6]. This dysregulation of emotions in early childhood may have lasting effects, as researchers have found insecurely attached children have greater difficulty understanding and regulating emotions [29].

The emotional climate of the family during infancy and childhood sets the stage for parent-child interactions throughout adolescence. A secure attachment and high levels of positive parent-child interactions are associated with greater adolescent emotion knowledge and regulation, whereas high levels of negative parent-child interactions are related to adolescent emotion dysregulation [42]. For example, Liew et al. [35] found that in adolescents, parental support of appropriate levels of autonomy is related to more positive emotionality and greater self-control. By contrast, greater parental psychological negative control is associated with higher levels of emotion dysregulation [63], suggesting ER difficulties.

The emotional climate of the family and its influence on parenting behaviors may also lead to disruptions in a child's neurobiological development. In families with high levels of expressed negative emotion, children often exhibit elevated cortisol levels, which represents activation of the hypothalamus-pituitary-adrenal (HPA) axis [30]. Chronic HPA axis activation can cause lasting effects on brain development [38]. We propose that the family emotional climate influences the activity in brain regions such as the amygdala, anterior insula, and the ACC. Swain's [57] model of "The Parental Brain" suggests that these regions (i.e., amygdala, insula, and cingulate) are important for parents' emotional drives and for directing appropriate responses to their children's needs. For instance, a study by Barrett and colleagues [5] found that amygdala activation in mothers was associated with viewing positive pictures of their own baby, while subgenual ACC (sgACC) activity was associated with viewing negative pictures of their baby. Additionally, previous literature suggests that mothers demonstrate activation in regions including the anterior insula and ACC in response to their infant's cry sound [32]. However, this response is not observed in depressed mothers [32]. Negative emotionality and mental health symptomatology may therefore adversely impact adaptive parenting responses. Overall, these findings highlight the potential importance of the amygdala, anterior insula, and ACC in parenting behavior and emotional responses.

5. Cognitive advances in emotion regulation and emotional intelligence

Beginning in infancy and toddlerhood, cognitive strategies such as shifting attention away from emotionally distressing stimuli, increasing awareness of emotions, and language development promote ER and emotional intelligence [9,19]. These developments allow for young children to accurately identify their emotions and communicate to others how they are feeling as well as to manage emotionally distressing situations. During infancy, the brain's orienting network, which includes parietal regions and the frontal eye fields, allows for focus on sensory stimuli. Often employed as one of the first ER strategies, the orienting network allows the infant to shift attention away from emotionally distressing stimuli [52]. In studies of attention orienting, infants with higher levels of orienting behavior showed less negative affect and increased surgency [52,18]. During this developmental stage, parents may promote this attention orienting, such as by directing the infant's attention away from the distressing stimulus and toward a toy.

In childhood, several cognitive advances might pave the way for self-regulation of emotions, including increases in independence, inhibitory control, and problem-solving techniques [56]. During this developmental period, a greater reliance on the executive attention network influences effortful control and ER. Interacting with the limbic system, the executive attention network allows the child to manage positive and negative emotional responses to various stimuli, and high levels of effortful control have been shown to be related to less negative emotions [52]. Parents can support the development of ER at this stage through teaching, emotion coaching, and socialization.

Adolescence is often accompanied by changes in perceptions of self and others, leading to increases in perspective-taking as well as awareness of others' emotions [2]. Adolescence is also marked by high levels of emotionality, socialization, and novel affective experiences [22]. Advances in cognitive and social-cognitive processes during adolescence are accompanied by developmental changes in several regions of the brain including the amygdala, striatum, insula, ACC, and regions of the PFC [22]. Cognitive reappraisal - the ability to alter one's thoughts and reframe experiences - is a critical ER strategy used during this developmental period. Gross [20] found that reappraisal is an effective strategy for reducing negative emotions in adolescence and later in adulthood, and the PFC has been implicated in neuroimaging studies of adolescents examining the use of cognitive reappraisal strategies during emotionally distressing tasks [22]. Adolescents also exhibit heightened emotional lability, internalizing and externalizing symptoms, and risky behavior, as compared to both children and adults [54]. Evidence suggests that these issues during adolescence may result from an imbalance in the rate of development of prefrontal circuitry required for ER and limbic circuitry underlying emotional reactivity [1]. Adolescents thus continue to need parental support as the neurocircuitry underlying ER continues to develop through young adulthood.

6. Dyadic influences on the development of emotion regulation

The influence of the parent-child relationship on the development of ER can be more fully understood by examining the neurobiology underlying ER and viewing ER from a dyadic perspective. Specifically, the parent-child relationship has been implicated in children's symptoms of depression and anxiety [36,46] and is often a successful intervention target [64]. A recent study examining the impact of maternal praise and criticism in a sample of high-risk adolescent girls found greater symptoms of depression and anxiety were associated with increased activation to maternal criticism in the right amygdala, whereas decreased activation in the right amygdala was associated with maternal praise responses [3]. In a similar study with healthy adolescents, researchers found that adolescents, in response to maternal criticism, exhibited increased activation in affective networks, specifically in the lentiform nucleus and posterior insula [33]. However, in these same adolescents, maternal criticism was associated with decreased activation in the dlPFC and caudal anterior cingulate cortex (cACC) as well as the temporoparietal junction and posterior cingulate cortex, regions typically associated with the cognitive control networks and the social control networks, respectively [33]. Lee and colleagues [33] propose decreased activation in the cognitive control and social control networks may be a result of adolescents' detaching themselves from maternal criticism, decreasing the likelihood of effective conflict resolution. Findings from these studies suggest the importance of the quality of parent-child interactions in adolescent ER and its effects on adolescent psychopathology.

As described above, parenting practices and the family environment have significant effects on an adolescent's emotional development. There are few studies thus far, however, that examine how parenting influences the development of neurocircuitry underlying ER and emotional intelligence. Parenting practices have been shown to predict the structural development of various frontal regions and the amygdala across adolescence [53,65,66], although many of these structural findings are specific to males. With regard to functional neuroimaging findings, maternal warmth appears to attenuate children's amygdala activation in response to fearful faces [51], suggesting that supportive, maternal parenting behavior may mitigate the impact of negative emotional stimuli in adolescents, further promoting ER. Another recent study found that parental difficulties in ER were related to their adolescent children's brain responses when viewing negative emotional stimuli [61]. Additionally, parental psychological control has been found to be negatively correlated with children's anterior insula activity during an emotion conflict task and was also associated with less accurate responding during the task [39]. With regard to connectivity, a recent study by Lee, Miernicki, and Telzer [34] found that parent-adolescent dyads with similar resting-state networks also had similar daily emotional synchrony as measured by ecological momentary assessment. Furthermore, adolescents who exhibited this synchrony with their parents also had higher levels of emotional competence, suggesting parental influence on adolescent ER. Similar to Swain [57], a review by Feldman [13] suggests additional evidence for the "parental brain." Comprised of regions associated with caregiving, empathy, and ER, the parental brain may allow for the development of parent-child biobehavioral synchrony, which in turn may influence the child's developing ER. Thus, there is some evidence that parenting practices and the familial environment affect children's development of ER neurocircuitry, but additional studies are needed in order to further delineate these effects.

Based on current research findings, we propose a model (Fig. 1) demonstrating how parent-child interactions and parent ER neurocircuitry may affect the development of children's ER neurocircuitry. We specifically focus on associations between prefrontal regions, the anterior insula, and the amygdala. In the model, we posit that parents' prefrontal inhibition circuitry affects the child's emotion processing regions in such a way that parents may regulate their child's emotions through parental behaviors that occur within the context of the parent-child relationship. This in turn affects the child's ER, and over time, with a sufficient balance between autonomy and guidance, children enhance their emotional intelligence and learn to regulate their own emotions through further development of prefrontal cortical regions and the anterior insula. Our model suggests that the ability of children and adolescents to regulate their own emotions is impacted by parenting practices through their effects on the development of ER-related neurocircuitry.

While we have attempted to integrate neuroscientific findings on parenting and the development of ER into a coherent model, past research studies contain a variety of limitations that highlight the need for further research. For example, studies of the effects of parenting practices on child brain structure and function suffer from genetic confounds. Most studies only report brain-related data on the child. It is entirely possible, however, that aberrant brain function in the child may have been genetically inherited from the parent, who also shares this aberrant brain function, which in turn underlies the poor parenting behaviors. Future studies could address this limitation in a number of ways, such as by scanning both the parent and child, comparing adoptive to biological parents, and/or examining the effects of interventions designed to change parents' behavior. Additionally, many brain regions cited here have a number of functions that are not specific to ER. The dlPFC is associated with a variety of other cognitive tasks, including memory [4] and decision-making [24,48], and nearly all prefrontal regions have some role in maintaining attention to a stimulus

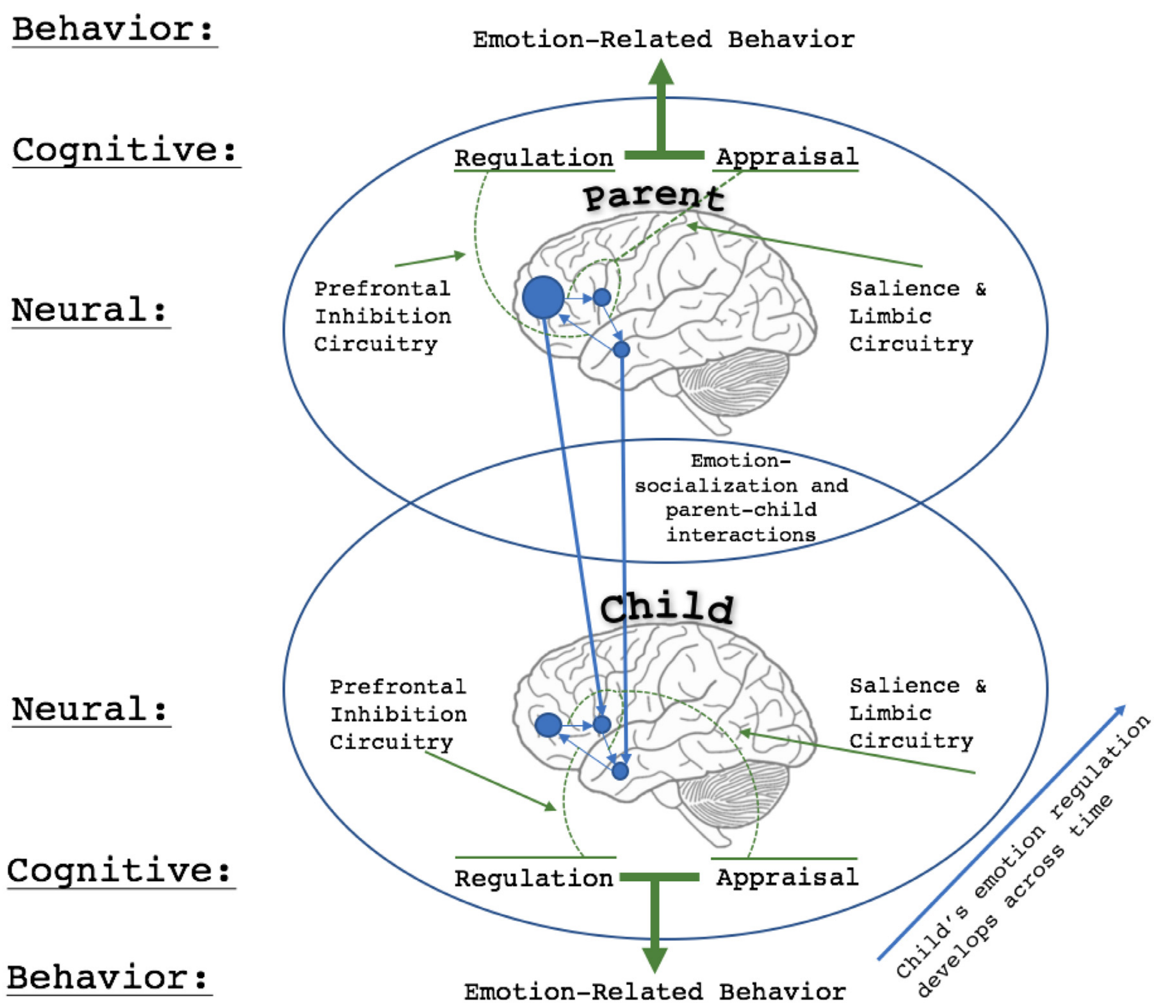

Fig. 1. Parent-child emotion regulation circuitry that influences emotional regulation. Blue circles represent the dorsolateral prefrontal cortex, anterior insula, and amygdala. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[31]. Thus, interpretations of individual differences in these regions are based on the experimental paradigms and prior research, but alternative explanations are possible.

Another major limitation of most neuroimaging studies to date is that they have either examined individual differences within a single sample of adolescents or cross-sectionally compared adolescents to adults. Cross-sectional studies, while informative, are typically correlational and thus do not allow for causal inferences. Longitudinal studies across the entire child and adolescent period are needed to examine how parenting influences the development of ER skills and emotional intelligence across time. Additionally, sex differences have been found in cross-sectional studies, and longitudinal studies may help determine if these differences are due to different rates of maturation and/or pubertal status versus the effects of gender socialization. This limitation is partially due to the relatively recent development of neuroimaging technologies compared to more traditional observational methods; longitudinal studies are currently ongoing whose results will further inform the field. For example, the Adolescent Brain Cognitive Development Study (ABCD) is the largest longitudinal study of youth brain development in the United States and includes the use of fMRI and biological specimen collection as well as expansive measures of physical, mental, and behavioral health [62]. The ABCD Study has recently completed baseline data collection, and future results from this longitudinal study will increase our understanding of the development of ER and its relation to parenting.

7. Advances in research and next steps

While much progress has been made in the study of the development of neurocircuitry underlying ER in childhood and adolescence, many questions remain. More ecologically valid tasks are needed that require children to regulate their emotions implicitly, rather than explicitly instructing them to do so in a certain manner. Such studies will have increased applicability to how children regulate their emotions in daily life. Also, in addition to strategies typically studied in experimental paradigms, there are many other types of both positive (e.g., acceptance, problem-solving) and negative (e.g., denial, self-injurious behavior) strategies that children and adolescents use to regulate their emotions [25]. Further expanding the scope of what is included in ER studies may help elucidate ways to improve the development of positive ER skills during childhood and adolescence.

Recently, fMRI technology has been employed to examine the effects of parent-child emotional interactions in real-time on adolescent brain responses [64,33]. These studies provide crucial insights into the usefulness of ER strategies throughout development. Hyperscanning, an fMRI technology that allows for the concurrent scanning of two socially interacting individuals [40], also offers a groundbreaking approach to examining brain activity related to ER during social interactions in both the parent and the child. Future studies utilizing advanced neuroimaging technology will increase our understanding of the neurobiological mechanisms underlying ER and emotional intelligence and serve to inform future intervention and prevention programs aimed at promoting healthy parent-child interactions.

In conclusion, examination of the development of ER and emotional intelligence within the context of the parent-child relationship would allow for the identification of neural targets for interventions aimed at correcting and protecting against psychopathology. Research suggests parent-child interventions focused specifically on ER could mitigate the development of emotional disorders and support healthy brain development and function [64–66,51]. Effective intervention strategies might include teaching effective ER techniques to both parents and children. Instructing parents and children to focus on physiological reactions to stress within themselves and others could increase awareness of emotional states and help regulate responses to stimuli. Specifically, techniques such as mindfulness training and fMRI neurofeedback have been shown to help individuals regulate amygdala activation, thereby reducing emotional distress and reactivity [69, 68]. Additionally, interventions focused on teaching effective emotion coaching strategies and supportive parenting techniques to parents could improve parent-child relationships. Increasing our understanding of the neurocircuitry underlying ER development and parenting will thus continue to inform prevention and intervention efforts to improve the lives of children and families.

Conflict of interest

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest. Kyle Simmons is an employee of Janssen Research and Development, LLC., Johnson and Johnson Inc. All other authors have no competing interests to declare.

Author contributions

All authors have made substantial contributions drafting the article, revising it, and approved of the final version to be submitted.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tine.2019.100118.

Appendix

Fig. 1.

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