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Research paper

Differential role of negative and positive parenting styles on resting-state brain networks in middle-aged adolescents

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ABSTRACT

Parenting styles encompass negative and positive approaches, potentially affecting adolescents' brain reward and emotion regulation systems. However, the association between parenting style and brain networks remains unknown. This study investigates the link between parenting style and functional connectivity (FC) within the reward and emotion regulation brain networks, using resting-state functional magnetic resonance imaging (rs-fMRI). A total of forty-two middle-aged adolescents (26 males; 16 females) with no neurological or psychiatric symptoms participated in this study. We assessed parenting behaviors and extracted reward/emotion regulation FC from rs-fMRI. We examined the association between FC and parenting style, identified through principal component analysis. Correlation analysis investigated these links while controlling for sex. We delineated both positive (love-autonomy) and negative (hostility-control) parenting styles, accounting for 79 % of the explained variance in parenting behaviors. The negative parenting style displayed connections with FC within the reward system, particularly in the left nucleus accumbens (NAc), showcasing links to multiple frontal regions. Furthermore, it correlated with the social reward network, specifically the insula-NAc FC in bilateral hemispheres. Conversely, the positive parenting style exhibited an association with FC between the hippocampus and right lateral prefrontal cortex. Our findings support negative parenting's association with an immature reward system and suggest positive parenting's potential to enhance emotion regulation in brain function. These observations highlight two distinct parenting styles, including single-parenting behaviors. Thus, we advance understanding of each style's unique contributions to adolescent reward- and emotion regulation-related brain network development.

1. Introduction

Adolescents undergo diverse experiences and develop effective coping mechanisms through consistent parental interaction. During these interactions, parenting behavior patterns emerge as significant environmental factors affecting the mental health of adolescents (Belsky and de Haan, 2011; Ford et al., 2023). Previous studies have reported that parental sensitivity and warmth can serve as protective or buffering factors for mental health development (Butterfield et al., 2021; Faure et al., 2017), whereas harsh parenting behaviors can negatively affect mental health (Choi and Becher, 2019). A growing body of research has also highlighted the relationship between parenting behaviors and mental development through investigations into underlying biological mechanisms (Whittle et al., 2017). Given that the adolescent brain is in a dynamic developmental phase, brain imaging studies can provide clues into the critical role of parenting behaviors in shaping mental health trajectories.

Previous studies showed that negative or positive parenting behaviors can impact brain volume development and functional connectivity (FC) across multiple brain regions in adolescents, which can lead to a

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healthy or vulnerable psychological state (Holz et al., 2018; Whittle et al., 2014). Notably, some findings have highlighted that negative parenting behaviors are associated with the development of an immature reward system in the brain (Choi et al., 2018; Seitz et al., 2023), whereas positive behaviors can lead to improved emotion regulation systems in the brain (Pozzi et al., 2020). The role of rewards is especially relevant in parent-adolescent interactions, where adolescents learn responses to specific situations through parental feedback such as compliments or punishments. Several investigations have revealed that maltreated adolescents may display impaired responses to reward stimuli and less positive assessments of reward cues in decision-making tasks (Dillon et al., 2009; Guyer et al., 2006). Conversely, parental warmth has been found to predict adolescent brain function, anxiety, and depressive symptoms two years down the line (Butterfield et al., 2021).

These neuroimaging studies have revealed significant associations between parenting behaviors and brain functions related to reward processing and emotional regulation. Notably, within the reward system, the basal ganglia play a prominent role in reward processing, reinforcement, and addictive behaviors (Schneider et al., 2014). Berns et al. (2001) reported that the basal ganglia and frontal brain activity responds to future rewards irrespective of specific preferences. A recent functional magnetic resonance imaging (fMRI) study uncovered decreased interactions between the basal ganglia and frontal regions in individuals experiencing aggressive maternal behavior and antipathy (Seitz et al., 2023). In line with this finding, another fMRI investigation demonstrated that hostile maternal behavior predicts FC strength between these regions (Kopala-Sibley et al., 2020).

Within the basal ganglia, a group of nuclei, the nucleus accumbens (NAc) is pivotal for processing reward and aversion information (Breiter et al., 2001; Gasic et al., 2009; Whittle et al., 2016). It is widely recognized as a central hub for social reward, interplaying with the insular cortices (IC) (Bellone et al., 2022). Research by Hardin et al. (2009) highlighted that the NAc exhibits heightened responsiveness to favorable outcomes, defined as rewards in tasks, while the IC shows salient responses when anticipating unfavorable outcomes. Within the IC-NAc pathway, the NAc receives cortical projections from the IC (Hirose et al., 2021), influencing social and emotional behaviors (Rogers-Carter et al., 2019). Given its role in the social reward system, investigations are exploring the relationship between IC-NAc functional connection and parenting style.

While a substantial number of studies have reported the effects of negative parenting on adolescents' characteristics, such as behavioral responses and brain activity, there is little research on the relationship between positive parenting and these characteristics. Nevertheless, several behavioral and neuroimaging studies have investigated the effects of positive parenting during adolescence. Morris et al. (2017) theorized that parenting is a key factor in development of emotional regulation during childhood and adolescence. Some articles documented that maternal supportive and positive behaviors influenced adolescents' emotion regulation response, prosocial behavior, and depressive symptoms (Ratliff et al., 2023; Yap et al., 2010).

Interestingly, evidence supports a robust link between positive parenting and the hippocampal volume development (Luby et al., 2013; Luby et al., 2012; Wang et al., 2019). The hippocampus is a crucial brain region in the context of emotional regulation. In addition, it has been found that the hippocampus is associated with emotion dysregulation and plays a role in consolidating emotional memory (Barch et al., 2019; Pronier et al., 2023). Moreover, increased hippocampal-medial prefrontal FC has been associated with enhanced emotion regulation following family interventions encompassing emotional support, monitoring, and communication skills (Hanson et al., 2019). This underscores the role of hippocampal-lateral prefrontal FC in emotional regulation and long-term affective responses, extending to broader domains of emotion regulation (Anderson and Floresco, 2022).

While adolescence generally refers to individuals aged 10 to 21 years, researchers segment adolescence into early, middle, and late periods to better understand overall development. As various biological, environmental, and social events occur during each stage, different abilities and characteristics develop at that stage. Middle adolescence is particularly an important stage that marks the onset of more refined cognitive abilities and identity formation. Given the critical nature of middle adolescence, a period characterized by higher-order thinking and identity construction, we investigated the links between parenting styles and brain activity related to reward processing and emotion regulation using resting-state fMRI data in middle-aged adolescents. We formulated two primary hypotheses: first, that a negative parenting style may be associated with abnormal functioning of the reward system in the human brain, and second, that a positive parenting style could exhibit associations with brain activity involved in emotional regulation. These hypotheses suggest that different parenting style uniquely affect the development of specific brain functions, particularly those related to reward processing and emotional regulation.

To parcellate parenting behaviors into positive and negative styles, we applied principal component analysis (PCA) to extract meaningful patterns from the four maternal behaviors: love, hostility, autonomy, and control. We hypothesized associations with three key brain networks: the basal ganglia–frontal and IC-NAc networks, both known to be responsible for reward system, and the hippocampal-lateral prefrontal cortex, related to emotional regulation. All procedures are summarized in Fig. 1.

2. Material and methods

2.1. Participants

A total of forty-two middle-aged adolescents, aged 13 to 17 years, were recruited as community samples through the distribution of flyers at schools and libraries in Seoul, South Korea (age = 14.88 ± 1.35; 26 males [61.9 %]). The adolescents' parents reported four types of parenting behaviors: the mean (SD) of love, hostility, autonomy, and control behaviors were 46 (6.939), 31.357 (6.588), 43.214 (4.257), and 41.191 (4.413), respectively. Table 1 presents detailed information on the demographic and clinical variables. Participants were required to be medically healthy. Exclusion criteria encompassed a history of neurological disorders, psychiatric and developmental disorders, language disorders, learning disabilities, or uncorrected sensory impairments. Before conducting the study, both the children and their parents provided written informed consent. This study was performed in accordance with the guidelines of the Helsinki Declaration and received approval from the Institutional Review Board for Human Subjects of Seoul National University Hospital, South Korea (IRB number: No. C-1412-081-633).

2.2. Measures

2.2.1. Parenting behavior

Parenting behavior was measured using the Maternal Behavior Research Instrument (MBRI) (Schaefer et al., 1959), which comprises four distinct psychological measures: love, hostility, autonomy, and control. Each measure comprises 12 items rated on a Likert scale ranging from 1 to 5. It defines parenting behaviors using two axes: love-hostility and autonomy-control (Bae, 2005; Lee, 1983).

2.2.2. Psychiatric symptomatology

The association between parenting behaviors and depression/anxiety levels was also examined. These factors were scored using the Children Depression Inventory (CDI), which comprises 27 items (Kovacs, 1983), and the State-Trait Anxiety Inventory-Children (STAI-C), which comprises 20 items (Spielberger et al., 1973). CDI scores were divided into four categories according to the severity of depression: normal (≤21), mild (22–25), moderate (26–28), and severe (≥29). All

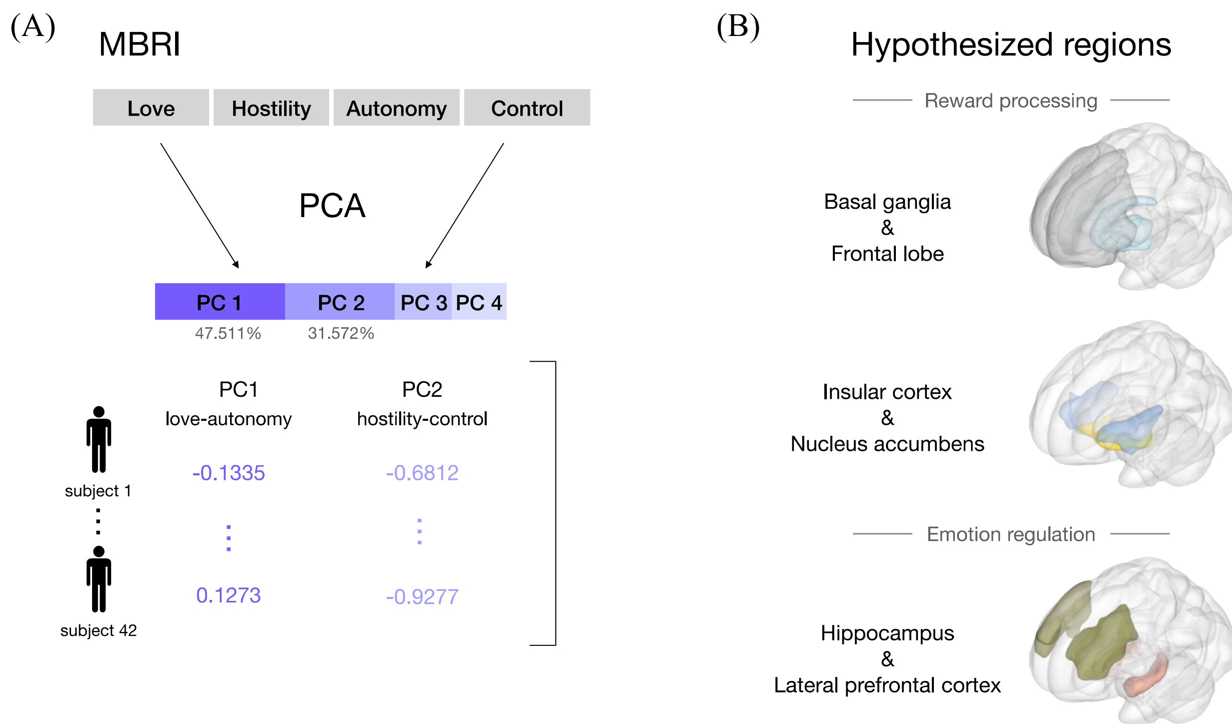

Fig. 1. Schematic of the study procedure. (A) Principal component analysis (PCA) was applied to Maternal Behavior Research Instrument (MBRI) subscales. The first and second components were selected, accounting for 79.083 % of the total explained amount. (B) Specific brain regions hypothesized to be associated with different parenting styles. These regions were color-coded distinctly.

Table 1
Demographic and clinical characteristics of the included middle-aged adolescents.

Characteristic	Mean	SD
Age	14.881	1.347
Sex, No. (%)		
Male	26 (61.9 %)	–
Female	16 (38.1 %)	–
MBRI		
Love	46.000	6.939
Hostility	31.357	6.588
Autonomy	43.214	4.257
Control	41.191	4.413
STAI-C		
Trait	29.842	8.474
State	33.184	5.362
CDI	19.707	6.776

Abbreviations: SD, standard deviation; MBRI, Maternal Behavior Research Instrument; STAI-C, State-Trait Anxiety Inventory-Children; CDI, Children Depression Inventory.

factors were translated and validated in the Korean version (Cho and Lee, 1990; Kim, 1978).

2.2.3. fMRI data acquisition

Brain MRI data were obtained using a 3.0 Tesla scanner (MAGNETOM et al.; Siemens et al.). Resting-state fMRI (rs-fMRI) data were obtained using the following parameters: repetition time (TR) = 3000 ms, echo time (TE) = 40 ms, flip angle (FA) = 90°, matrix size = 128 × 128, voxel size = 1.88 × 1.87 × 4.8 mm, field-of-view (FOV) = 241 × 240 mm, and number of volumes = 190. In addition, high-resolution T1-weighted images were obtained using a magnetization-prepared rapid acquisition gradient echo (MPRAGE) pulse sequence using the following parameters: TR = 1900 ms, TE = 3.13 ms, FA = 9°, voxel size = 0.898 × 0.898 × 0.9 mm, and FOV = 230 × 201 mm. A foam pad was used to minimize the effect of artifacts in head motion. All participants were instructed not to sleep and to focus on specific thoughts during the rs-fMRI scanning.

2.3. Analyses

2.3.1. Processing of rs-fMRI data

The rs-fMRI data were preprocessed by means of canonical procedures using the statistical parametric mapping toolbox (Friston et al., 1994) (SPM12, http://www.fil.ion.ucl.ac.uk/spm/, Wellcome Trust Centre for Neuroimaging, London, UK). Specifically, the preprocessing steps included: 1) discarding the first three scans to achieve equilibrium in the MRI time series, 2) performing slice timing correction for different acquisition times across each slice, 3) realigning the images to correct for rigid head motion, 4) co-registering the resulting neuroimages to the gray matter map segment of individual T1-weighted data, 5) normalizing the images into standard stereotactic Montreal Neurological Institutes (MNI) space, and 6) smoothing the normalized images using an isotropic three-dimensional Gaussian kernel with 6 mm full-width at half-maximum (FWHM).

Negative parenting style was analyzed using FC between the basal ganglia and frontal regions and between the insular and nucleus accumbens, while positive parenting style was investigated using FC between the hippocampus and lateral prefrontal areas. These regions of interest (ROIs) were defined using the Schaefer 200 for frontal regions (Kong et al., 2021) and the Brainnetome atlases for other subcortical regions (Fan et al., 2016). The brain regions delineated using the Shaefer 200 atlas were defined according to the distribution of FC, where regions were subdivided into more detailed functional areas, such as subregions responsible for salience ventral attention (SVA) and somatomotor (SM) function within the IC, and control (Cont) function within the lateral prefrontal cortex (PFCl).

Regionally averaged fMRI time series were extracted for each ROI and preprocessed with the following conventional procedures: (1) linear detrending, (2) regressing out the effects of six rigid movements, their derivatives, and five principal components of the white matter and cerebrospinal fluid (CSF) mask, (3) spike detection and despiking with four times of the median absolute deviation, and (4) band-pass filtering (0.01–0.1 Hz) to estimate low-frequency fluctuation of rs-fMRI signals (Power et al., 2012; Taylor et al., 2014; Thomas et al., 2014; Weissenbacher et al., 2009). The Pearson correlation coefficient was calculated for the time series at two distinct regions to measure FC. All correlation values were normalized using Fisher's r-to-z transformation.

2.3.2. Statistical analysis

Principal component analysis (PCA) was used to identify meaningful combinations of the four parenting behaviors (Appendix S1). Partial correlation analyses were performed to investigate the relationships between these PC scores (latent parenting styles) and the strength of the FC between each pair of brain regions (covariate = sex). Additionally, we conducted Pearson correlations among parenting factors and psychiatric symptoms, including the PC scores representing latent parenting styles, four specific parenting behaviors, and measure of depression and anxiety. Moreover, a partial correlation analysis was performed, controlling for sex as a covariate, between FC strength for each network and the aforementioned factors. The analysis of variance test was also used to examine whether PC scores differed based on the levels of depression and anxiety. A false discovery rate (FDR) < 0.05 was used to address the multiple testing problem. All statistical analyses were performed using MATLAB-based custom software (MathWorks et al., USA).

3. Results

3.1. Parenting style identified with PCA

Primary and secondary PCs were identified, collectively explaining 79.08 % of the variance. The primary PC primarily represented a positive parenting style, mainly encompassing love and autonomy behaviors. Meanwhile, the secondary PC depicted a negative parenting style characterized by hostility and control. Details of PC scores and their corresponding explained variances for each PC are presented in Fig. 2.

3.2. fMRI results

3.2.1. Relationship between parenting styles, parenting behaviors, and psychiatric symptoms

To explore the association between parenting factors and psychiatric symptoms, we conducted correlation analyses among parenting styles, the four parenting behaviors, and psychiatric symptoms. Table 2 summarizes these relationships. The positive parenting style (love-autonomy) shows positive correlations with both love and autonomy in parenting behaviors. Conversely, this positive parenting style is negatively associated with parental hostility. In contrast, negative parenting styles exhibit positive associations with both hostility and control behaviors. These results indicate that parenting styles align with corresponding positive and negative parenting behaviors. Significant relationships were observed among these parenting behaviors. Love in parenting behavior is negatively associated with hostility, while it shows a positive relationship with autonomy. Furthermore, a negative relationship was identified between hostility and autonomy in parenting behaviors. Additionally, trait anxiety showed a positive correlation with state anxiety.

3.2.2. Relationship between brain FC and other factors

Partial correlation analyses were conducted between brain FC and other factors. The results revealed significant associations between four FCs within the NAc and insula networks and the control parenting behavior. Notably, other parenting behaviors, including love, hostility, and autonomy, showed no significant relationships with either parenting or psychiatric factors (see Table 3).

3.2.3. Association between parenting styles and brain FC

Correlations between negative and positive parenting styles and FC among the hypothesized regions were analyzed with an FDR threshold of <0.05. All results, including the correlations and p-values, are listed in Table 4 and Fig. 3.

A negative parenting style was significantly associated with FCs in the left NAc, which was linked to the left inferior frontal gyrus (IFG, $r = 0.601$), right frontal operculum (FrOper, $r = 0.584$), and right PFCl ($r = 0.570$). It was also associated with the FC between the right NAc and left IFG ($r = 0.540$), as well as between the left ventral caudate and right PFCl ($r = 0.562$). In addition, the negative parenting style was found to be positively related to FCs between the NAc and subregions responsible for SVA and SM function within the IC in both hemispheres symmetrically (FC with the left NAc: $r = 0.470$, for the left SVA; $r = 0.422$, left SM; $r = 0.381$, right SVA; and $r = 0.512$, right SM; FC with the right NAc: $r = 0.395$, for the left SVA; $r = 0.370$, left SM; $r = 0.371$, right SVA; and $r = 0.454$, right SM) (Table 4). Higher scores on positive parenting style were associated with reduced FC between the bilateral caudal hippocampus and the subregions within the right PFCl responsible for Cont. This negative correlation was observed for both hemispheres ($r = -0.515$ for the left, $r = -0.481$ for the right).

Meanwhile, the four depression groups did not differ significantly in parenting style scores, where only two and one participants reported moderate and severe depression, respectively. In addition, no cutoff score for the STAI-C was found, and approximately 25 % of the STAI-C score was utilized as the cutoff to separate the groups. The two groups differed significantly in terms of parenting styles.

4. Discussion

In this study, we investigated the association between parenting behaviors and brain FC within the reward system and emotion regulation networks. We identified two major parenting styles: hostility-control parenting behavior (negative style) and love-autonomy parenting behavior (positive style). The positive style is significantly

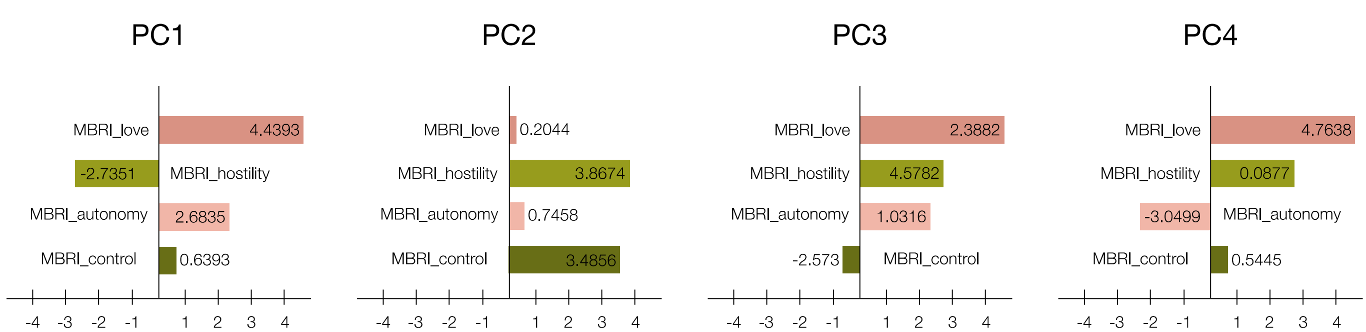

Fig. 2. Different combinations according to the principal components from four parenting behaviors.

Table 2
Associations between parenting styles, parenting behaviors, and psychiatric symptoms.

	Parenting style	MBRI				Psychiatric symptoms		
	Negative parenting	Love	Hostility	Autonomy	Control	STAI-C, Trait	STAI-C, State	CDI
Positive parenting	−0.059	0.876*	−0.611*	0.879*	0.141	−0.150	−0.166	0.048
Negative parenting	1	0.007	0.657*	0.090	0.888*	0.094	−0.026	0.069
Love		1	−0.373*	0.642*	0.104	−0.239	−0.196	−0.018
Hostility			1	−0.378*	0.273	−0.026	0.038	−0.095
Autonomy				1	0.157	−0.147	−0.135	0.025
Control					1	0.194	−0.026	0.163
STAI-C, Trait						1	0.623*	0.157
STAI-C, State							1	0.042

Abbreviations: MBRI, Maternal Behavior Research Instrument; STAI-C, State-Trait Anxiety Inventory-Children; CDI, Children Depression Inventory. * presents uncorrected *p*-values <0.05.

Table 3
Associations between parenting behavior and brain functional connectivity.

Insula-nucleus accumbens FCs					
Parenting behavior	Region	Region	r	p-value	FDR
Control	SVA.Ins-L	left NAc	0.413	7.26×10^{-3}	0.041
	SM.Ins-R	left NAc	0.422	5.94×10^{-3}	0.041
	SVA.Ins-L	right NAc	0.407	8.22×10^{-3}	0.041
	SM.Ins-R	right NAc	0.433	4.72×10^{-3}	0.041

Abbreviations: FC, functional connectivity; FDR, False discovery rate; L, Left hemisphere; R, Right hemisphere; SVA, salience ventral attention; SM, somatomotor; Ins, Insula.

associated with the strength of the hippocampal-lateral prefrontal FC, indicating emotional regulation function. In contrast, the negative style correlates with the frontal-basal ganglia FC and insula-nucleus accumbens FC within reward processing networks.

It is worth noting that preceding studies into parenting behaviors grounded in neuroimaging typically relied on observation-based tasks (Pozzi et al., 2021; Whittle et al., 2014) or self-report questionnaires (Brody et al., 2019; Jiang et al., 2021). However, task scores can inadvertently emphasize different dyadic interaction attributes due to varying scoring systems and time demands during mother-child interaction tasks. In addition, research utilizing self-report questionnaires mostly examined associations between single parenting behavior, such as maternal warmth and support, and brain characteristics. This differs from our approach, which encompasses a broader scope of measures related to individual parenting behaviors.

Positive correlations were revealed between negative parenting styles and FC in the frontal-basal ganglia. This indicates that when parents reported more negative parenting styles (hostility and control behaviors), their adolescents exhibited elevated activation of the frontal-basal ganglia FC. All significant frontal ROIs belonged to the SVA network, which is involved in making strategies to achieve effective goals considering situations and managing attention from distractions (Rueter et al., 2018). Particularly, the NAc showed significant associations with the frontal lobe regions, including the IFG, FrOper, and PFCl. It is a subregion of the basal ganglia involved in processing rewarding and reinforcing stimuli (Tottenham and Galvan, 2016) and is frequently reported as a vulnerable brain site for negative mental states (Rutherford et al., 2011).

Previously, frontal-basal ganglia FCs have been examined in relation to negative mental states, including addiction (Hanlon et al., 2011), depression (Furman et al., 2011), and anxiety (Manning et al., 2015), exhibiting abnormal connection strengths, such as hypo- or hyper-connectivity depending on the severity of the disorder. Bruno et al. (2022) proposed that the network's imbalance (hypo- or hyper-connectivity) is a compensatory consequence of structural alterations, particularly within these brain regions. Considering the results of this study and prior research, it is conceivable that a negative parenting style may influence FC during brain development, potentially serving as a significant factor in precipitating negative mental health.

Table 4
Association between parenting styles and brain functional connectivity.

Frontal-basal ganglia FCs					
Parenting style	Region	Region	r	p-value	FDR
Negative parenting (PC2)	PFCl-R	left ventral caudate	0.562	1.30×10^{-4}	0.020
	IFG-L	left NAc	0.601	3.27×10^{-5}	0.019
	FrOper-R	left NAc	0.584	6.16×10^{-5}	0.019
	PFCl-R	left NAc	0.570	1.01×10^{-4}	0.020
	IFG-L	right NAc	0.540	2.67×10^{-4}	0.033
Insula-nucleus accumbens FCs					
Parenting style	Region	Region	r	p-value	FDR
Negative parenting (PC2)	SVA.Ins-L	left NAc	0.470	2×10^{-3}	0.019
	SM.Ins-L	left NAc	0.422	6×10^{-3}	0.030
	SVA.Ins-R	left NAc	0.381	1.39×10^{-2}	0.043
	SM.Ins-R	left NAc	0.512	6×10^{-4}	0.013
	SVA.Ins-L	right NAc	0.395	1.06×10^{-2}	0.042
	SM.Ins-L	right NAc	0.370	1.73×10^{-2}	0.043
	SVA.Ins-R	right NAc	0.371	1.71×10^{-2}	0.043
	SM.Ins-R	right NAc	0.454	2.8×10^{-3}	0.019
Hippocampal-lateral prefrontal FCs					
Parenting style	Region	Region	r	p-value	FDR
Positive parenting (PC1)	left caudal hippocampus	Cont.PFCl-R	−0.515	5.71×10^{-4}	0.027
	right caudal hippocampus	Cont.PFCl-R	−0.481	1.44×10^{-3}	0.035

Abbreviations: FC, functional connectivity; FDR, False discovery rate; PC, principal component; R, Right hemisphere; L, Left hemisphere; PFCl, lateral prefrontal cortex; IFG, inferior frontal gyrus; FrOper, frontal operculum; SVA, salience ventral attention; SM, somatomotor; Ins, Insula; Cont, Control.

A significant enhancement in the FC between the left ventral caudate and right PFCl was observed. A recent study on attachment security found that children with higher child-reported attachment security scores exhibit decreased activation in caudate-prefrontal connectivity (Choi et al., 2021). Considering our results regarding negative parenting style, attachment security, which signifies a safe and stable interactive relationship between child and caregiver, emerges as a factor akin to parenting behavior. In this study, the positive relationship between negative parenting style and frontal-basal ganglia FC suggests that

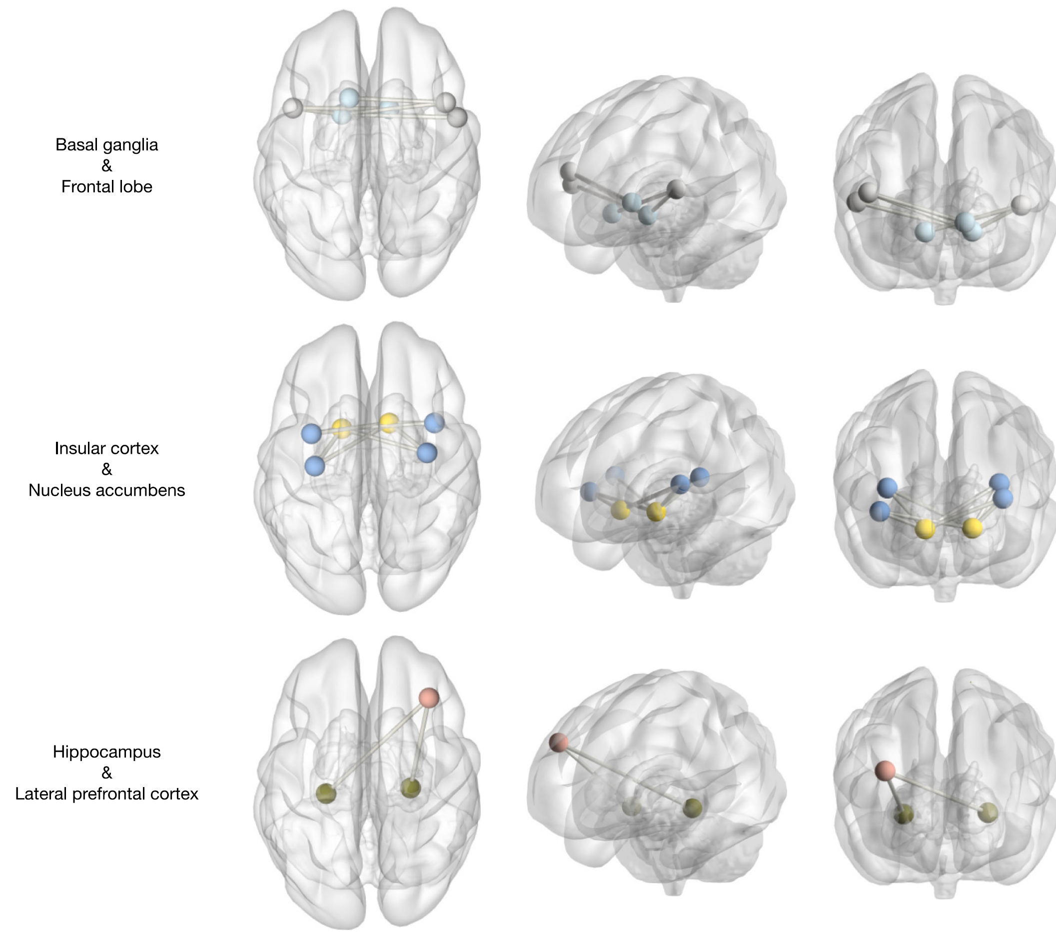

Fig. 3. Brain networks associated with the negative and positive parenting styles. Top and middle: Functional connectivity showing positive correlations with the negative parenting style. Bottom: Functional connectivity showing negative correlations with the positive parenting style. Each node corresponds to a distinct brain region, each of which is color-coded, as shown in Fig. 1.

hostile and controlling behaviors of parents contribute to abnormal frontal-basal ganglia FC within the brain's reward system.

Considering that family interactions constitute the initial steps of interpersonal communication, it is plausible that negative parenting behaviors may exert a stronger influence on the social reward system. Further research is needed to explore the specifics of the IC-NAc pathway in this context. Our results showed a significant positive association between negative parenting and IC-NAc FCs. It is noteworthy that adolescents subjected to more negative parenting behaviors reported heightened distress. The observed hyperactivity in IC-NAc FCs aligns with previous research demonstrating their vulnerability to stress (Rutherford et al., 2011).

Consistent with previous findings (Hanson et al., 2019), an association between positive parenting behaviors (love and autonomy behaviors) and FCs in the hippocampus and PFCl was found in this study. Several studies on parenting have shown that parental support and sensitivity lead to the development of a larger hippocampal volume or active response in the hippocampal FC, inferring healthy development of the hippocampus (Luby et al., 2012; Wang et al., 2019). In our study, negative relationships were observed between positive parenting style and FCs between the bilateral caudal hippocampus and right PFCl. This may imply that individuals exhibit attenuated connectivity between brain areas if their parents provide more love and autonomous behaviors. Given that FC aids the understanding of emotional responses (Anderson and Floresco, 2022), a positive parenting style may be intricately tied to emotion regulation.

These findings are consistent with our hypotheses by providing concrete evidence on parenting and reward/emotional brain systems (Choi et al., 2018; Choi et al., 2021; Holz et al., 2018). A positive correlation between negative parenting style and FCs involving the reward system was revealed, whereas a negative correlation between positive parenting style and caudal hippocampus-PFCl FCs was also found. These results suggest that parenting style has a differential impact on brain FCs. While the hostility-control parenting style affects the development of the brain reward system, particularly social rewards during middle adolescence, positive parenting behaviors may be related to emotional response regulation. This may support the plausible explanation that a few changes occurring in the human brain are coping strategies for long-term environmental factors, such as parenting style.

5. Limitations

This study had some limitations. First, while the observations were consistent with previous research, our study included a modest number of participants, warranting the need for larger samples in subsequent investigations. Second, participants consisted of middle-aged adolescents, recognizing that brain development occurs during childhood and adolescence. Future research may encompass participants across a broader age spectrum to ascertain whether the associations between parenting style and brain reward system FC endure into adulthood. Third, the MBRI was used to measure parenting behaviors. The participants' parents completed it, and we did not control for differences in parenting behaviors perceived by adolescents and their parents. Lastly, establishing a causal link between parenting style and brain FC was challenging due to the cross-sectional nature of the study's design.

6. Conclusions

Our findings reveal a correlation between parenting style and brain FC, particularly in relation to the reward system and emotion regulation. Adolescents exposed to more hostile and controlling parenting behaviors demonstrated increased FC in neural networks associated with reward processing. Conversely, higher levels of love and autonomous parenting behaviors were associated with decreased FC within brain areas responsible for emotion. These observations collectively indicate that parenting behavior exerts distinct influences on brain FC. As a result, our findings may provide a better understanding of the relationship between parenting style and brain development.

CRediT authorship contribution statement

Seulgi Lee: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Haemi Choi:** Data curation. **Min-Hyeon Park:** Writing – original draft, Supervision, Funding acquisition, Data curation. **Bumhee Park:** Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

All authors declared no conflicts of interest with respect to this research and the publication of this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2024.08.096.

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