Behavioral/Cognitive

Family Cohesion Moderates the Relation between Parent–Child Neural Connectivity Pattern Similarity and Youth's Emotional Adjustment

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Despite a recent surge in research examining parent–child neural similarity using fMRI, there remains a need for further investigation into how such similarity may play a role in children's emotional adjustment. Moreover, no prior studies explored the potential contextual factors that may moderate the link between parent–child neural similarity and children's developmental outcomes. In this study, 32 parent–youth dyads (parents: M_{age} = 43.53 years, 72% female; children: M_{age} = 11.69 years, 41% female) watched an emotion-evoking animated film while being scanned using fMRI. We first quantified how similarly emotion network interacts with other brain regions in responding to the emotion-evoking film between parents and their children. We then examined how such parent–child neural similarity is associated with children's emotional adjustment, with attention to the moderating role of family cohesion. Results revealed that higher parent–child similarity in functional connectivity pattern during movie viewing was associated with better emotional adjustment, including less negative affect, lower anxiety, and greater ego resilience in youth. Moreover, such associations were significant only among families with higher cohesion, but not among families with lower cohesion. The findings advance our understanding of the neural mechanisms underlying how children thrive by being in sync and attuned with their parents, and provide novel empirical evidence that the effects of parent–child concordance at the neural level on children's development are contextually dependent.

Key words: connectivity; pattern similarity; emotion; family; neural similarity; parent–child dyad

Significance Statement

What neural processes underlie the attunement between children and their parents that helps children thrive? Using a naturalistic movie-watching fMRI paradigm, we find that greater parent–child similarity in how emotion network interacts with other brain regions during movie viewing is associated with youth's better emotional adjustment including less negative affect, lower anxiety, and greater ego resilience. Interestingly, these associations are only significant among families with higher cohesion, but not among those with lower cohesion. Our findings provide novel evidence that parent–child shared neural processes to emotional situations can confer benefits to children, and underscore the importance of considering specific family contexts in which parent–child neural similarity may be beneficial or detrimental to children's development, highlighting a crucial direction for future research.

Introduction

Starting very early in life, children and their parents strive to develop attuned similarities at multiple levels as they serve as a foundation for children to navigate the complex world and resourcefully respond to the changing environment (Wheatley et al., 2012; Ainsworth et al., 2015). Drawing on extensive research on parent–child similarity at the behavioral, emotional, and physiological levels (e.g., Feng et al., 2007; Davis et al., 2017; DePasquale, 2020), an increasing literature provides evidence for the concordance between parents' and children's brain activities (e.g., EEG: Wang et al., 2018; fNIRS: Nguyen et al., 2020; Reindl et al., 2022) and suggests the protective role of such dyadic neural similarity in children's adjustment (e.g.,

Received Feb. 26, 2023; revised June 5, 2023; accepted June 6, 2023.

Author contributions: Z.Z., Y.-Y.C., B.Y., Y.Q., and T.-H.L. analyzed data; Z.Z., Y.Q., and T.-H.L. wrote the first draft of the paper; Z.Z., Y.-Y.C., B.Y., Y.Q., and T.-H.L. edited the paper; Z.Z., Y.Q., and T.-H.L. wrote the paper; Y.-Y.C. and T.-H.L. designed research; Y.-Y.C. and T.-H.L. performed research; Y.-Y.C. and T.-H.L. contributed unpublished reagents/analytic tools.

This work was supported by Virginia Tech Institute for Society, Culture and Environment research award; National Science Foundation BCS 1944644; and the Center for Culture, Brain, Biology, and Learning at Northwestern University.

The authors declare no competing financial interests.

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https://doi.org/10.1523/JNEUROSCI.0349-23.2023

lower stress, lower irritability, and better sleep quality) (fMRI: Lee et al., 2017a, 2018; fNIRS: Quiñones-Camacho et al., 2020). Yet, only limited research investigated how parent–child neural similarity may be associated with children's emotional adjustment (Qu et al., 2023). More importantly, no prior research considered the moderating role of family contexts in the links between parent–child neural similarity and children's development. Therefore, it is important to understand under what circumstances can parent–child neural similarity be beneficial to child development.

Parent–child neural similarity may not only provide a basis for children to form affiliative bonds and enduring attachment with their parents (Feldman, 2012; Davis et al., 2018), but also facilitate children's acquisition of emotional processing and regulating capacities through shared emotion-related processes with their parents (Atzil et al., 2014; Atzil and Gendron, 2017). Indeed, prior research found that neural profile similarity measured by parent–child resting-state connectome pattern was related to children's greater emotional competence (Lee et al., 2017b). Similarly, parent-child real-time brain-to-brain synchrony was associated with children's adaptive emotion regulation (Reindl et al., 2018), and greater functional connectivity between parents' and youth's brains (cross-brain connectivity) during interactions was associated with youth's fewer depressive symptoms (Ratliff et al., 2021). Drawing on this line of research, parent–child neural similarity may also play a role in other aspects of children's emotional adjustment, such as affective states (e.g., mood and anxiety) and abilities to recover from stressful events in life (i.e., ego resilience) (Block and Kremen, 1996).

Moreover, scholars have suggested that parent–child physiological similarity may not always be promotive and protective, especially in negative family contexts (Creavy et al., 2020). However, no empirical studies to date explored whether the effects of parent–child neural similarity on children's adjustment may also vary across family contexts. For example, when there is higher emotional bonding and support between family members, similar neural processes in parent–child dyads may be more likely to transform into better parent–child communication and coregulation processes in stressful situations, which can ultimately promote children's emotional well-being (Lindsey et al., 2009; Lunkenheimer et al., 2020). In contrast, when the family involves more negative interactions and emotional exchanges, parent–child neural similarity may not easily contribute to children's emotional adjustment. Therefore, children may benefit more from their neural attunement with their parents in positive family environments.

The current study aimed to examine the relations between parent–child neural similarity and children's emotional adjustment, and investigate whether family cohesion plays a moderating role in such relations. Compared with other neuroimaging techniques, fMRI has high spatial resolution, allowing researchers to pinpoint the precise location of brain activity. Moreover, beyond examining the regions of the cortex, fMRI has the capability to investigate neural activity in subcortical regions (e.g., amygdala) that play an important role in emotional processing, which is particularly useful when studying complex neural processes that involve multiple brain regions in response to emotional stimuli. Therefore, in the current study, both parents and their youth were scanned using fMRI when watching a movie, a naturalistic paradigm designed to evoke rich emotional processes. In particular, we focused on how similarly emotion network interacts with other regions at the whole-brain level (i.e., seed-based whole-brain connectivity similarity) to understand or respond to emotional situations between parents and their children. The brain expertly orchestrates its response to environmental stimuli by concurrently coordinating and synchronizing a multitude of operations within and across distinct brain regions and networks, akin to a harmonious orchestra (Buzsáki and Draguhn, 2004; Buzsáki, 2006). In other words, a given neural process is not strictly confined to a single region or network. Rather, it depends on the ability of the primary region or network associated with a particular task demand to allocate neural resources and communicate effectively with external regions and networks beyond the central one, ultimately facilitating task-specific processes. Therefore, we examined parent–child similarity in how the emotion network drives the use of neural resources during the information processing in the brain (e.g., Kim-Spoon et al., 2023). Drawing on prior research (e.g., Lee et al., 2017b; Reindl et al., 2018; Birk et al., 2022), we hypothesized that greater parent–child similarity in how emotion network interacts with other brain regions during movie viewing would be associated with less negative affect, lower anxiety, and greater ego resilience in youth. Moreover, we expected that the associations between parent–child neural similarity and youth's negative affect, anxiety, and ego resilience would be more salient among families with greater cohesion, but not among families with lower cohesion.

Materials and Methods

Participants and procedures

Participants were recruited by distributing flyers on Facebook groups, publishing advertisements in newspapers, and using local media. Participants were recruited from the New River Valley area, Virginia, without gender and race/ethnicity restriction. All participants provided written informed consent, and the study protocol was approved by the Institutional Review Board of Virginia Tech. Participants were excluded if they did not meet the safety standards in the MRI screening form. Exclusion criteria consist of the following: claustrophobia, history of head injury resulting in loss of consciousness for >10 min, orthodontia impairing image acquisition, severe psychopathology (e.g., psychosis), and other contraindications to MRI (e.g., pacemaker, aneurysm clips, neurostimulators, cochlear implants, metal in eyes, steel worker, or other implants). All exclusion criteria were assessed through self-report.

The final sample included 32 parent–youth dyads who participated in this study (parents: M_{age} = 43.53 years, SD = 7.30 years, range = 30-64 years, 72% female; youth: M_{age} = 11.69 years, SD = 2.80 years, range = 8-17 years, 41% female). Each parent was either mother or father who self-identified as the primary caregiver of their adolescent children. Among all parents, 94% were biological parents and 6% were adoptive parents. Regarding participants' race and ethnicity, 69% of youth self-identified as non-Hispanic White American, 16% as Hispanic American, 12% as non-Hispanic Asian American, 3% as non-Hispanic Black or African American; 81% of parents self-identified as non-Hispanic White American, 3% as Hispanic American, 13% as non-Hispanic Asian American, 3% as non-Hispanic Black or African American. Youth first completed self-reported measures on family cohesion, negative affect, anxiety, and ego resilience. Both youth and their parents underwent a resting-state fMRI scan, followed by a movie watching fMRI scan.

Movie watching during the scan. The participants, both parents and youth, were instructed to view an animated film, *Sonder* (14 min, 53 s, https://www.youtube.com/watch?v=3Cav2Uc_7Cs) during the scan. The movie focuses on the theme of emotional self-discovery and the various range of emotions, including happiness, sadness, confusion, and potentially even a sense of growth, that the main character experiences following the end of a significant relationship. The main character's emotions are depicted through actions, facial expressions, situations, as well as through symbolic representations and visual imagery. The movie was assumed to require participants' ability to understand diverse emotions as it used

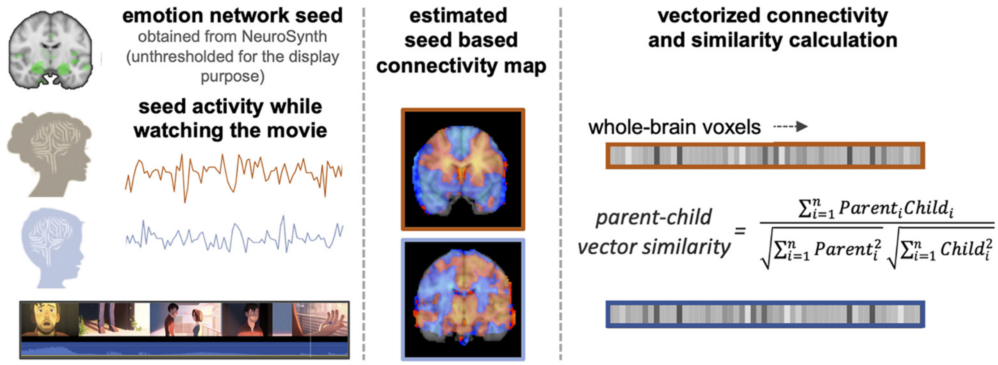

Figure 1. Schematic of analytical approach to vectorize functional connectivity maps and calculate the connectivity pattern similarity of the parent–child dyads based on the cosine distance.

several symbolic representations conveying emotion and meaning. For example, the plant was used as a symbol to represent the emotional journey of the main character, and the different states of various flowerpots were used to illustrate the changes and evolution of main character's significant relationship. The goal of using this affect-rich movie in our study was not to determine the accuracy of the participants' ability to interpret emotions through symbolic representations, but rather to see how similar parent–child pairs process and perceive the movie in their brains.

fMRI data acquisition and analyses

Data acquisition and preprocessing. All MRI data were acquired on a Siemens 3T PRISMA with a 64-channel matrix head coil located in Fralin Biomedical Research Institute at Virginia Tech Carilion. High-resolution T1 (TR = 2.5 s; TE = 2.06 ms; FA = 8°; 1 mm isotropic voxel; FOV = 256 mm) and T2 (TR = 3.2 s; TE = 563 ms; FA = 120°; 1 mm isotropic voxel; FOV = 256 mm) anatomic images were acquired for tissue segmentation (GM, WM, and CSF mask) and normalization. Functional images for the movie watching (393 volumes) and resting state (360 volumes) were acquired with gradient-echo echo-planar T2*-weighted imaging sequence (TR = 2 s; TE = 25 ms; FA = 90°; 2.5 × 2.5 mm resolution; 37 interleaved 3.0 mm slices with 0.3 mm gap; FOV = 92 mm). Preprocessing was performed using the FMRIB Software Library (FSL) (Jenkinson et al., 2012), ICA-AROMA toolbox (Pruim et al., 2015), and ANTs library (Avants et al., 2009). The excessive motion was identified based on an average of 0.5 mm frame displacement, and no participants were excluded. Aggressive ICA-AROMA was used for physiological noise correction, given its proven efficacy in eliminating physiological fluctuations in the absence of simultaneous recordings (Scheel et al., 2022). Preprocessing for the movie watching session included the first two volumes cut, high pass filter (128 s; 0.0078 Hz), motion correction (mean relative motion = 0.1012 mm; mean absolute motion = 0.975 mm), 5 mm smoothing, slice-timing correction, grand-mean intensity normalization, ICA denoising (corrected FD mean = 0.026 mm; corrected DVAR mean = 5.897), and registration to standard MNI 2 mm brain template. Preprocessing for the resting state was identical but included bandpass filter (0.001-0.08 Hz) with mean CSF/WM signal as nuisance regressors extracted within individually segmented masks at 90% threshold), the first 10 volumes cut, and ICA denoising (mean relative motion = 0.106 mm; mean absolute motion = 0.679 mm; corrected FD mean = 0.030 mm; corrected DVAR mean = 6.226).

Estimation of parent–child neural connectivity pattern similarity with emotion network seed. The primary interest of the current study was how similarly emotion network interacts with other brain regions to understand or respond to emotional situations between parents and their children. To this end, we first estimated emotion network seed-based connectivity maps for each individual using *a priori* network seed (e.g., Lee et al., 2019), selected based on the union of association and uniformity inference maps (e.g., Woo et al., 2014) associated with "emotions" and "emotional response" terms at $Z = 5.2$ threshold level from the automated large-scale meta-analytic database of >444 published neuroimaging studies (http://neurosynth.org) (Yarkoni et al., 2011), yielding various regional voxels, including amygdala (L: $x = -22$, $y = 2$, $z = -23$; R: $x = 23$, $y = -1$, $z = -24$), temporal pole (L: $x = -50$, $y = 2$, $z = -24$; R: $x = 23$, $y = -1$, $z = -24$), frontal orbital cortex (R: $x = 44$, $y = 28$, $z = -10$), inferior frontal gyrus (R: $x = 52$, $y = 29$, $z = 2$), frontal pole (L: $x = -8$, $y = 60$, $z = 32$), insula (L: $x = -37$, $y = -4$, $z = -6$), temporal fusiform gyrus (R: $x = 43$, $y = -52$, $z = -17$), thalamus (L: $x = -1$, $y = -26$, $z = 2$), and anterior cingulate cortex ($x = 7$, $y = 44$, $z = 8$). The reported coordinates are based on the highest Z value within the Harvard-Oxford Atlas. The seed-based connectivity estimation was done by FSL's dual regression function with the seed network mask.

It is worth noting that our examination focused on how the emotion network regions interacted with other brain regions at the whole-brain level involved in comprehending the movie, rather than on the connections within the emotion network. After estimating the connectivity maps using the emotional network seed, we calculated the pattern similarity across all voxels at the whole-brain level, which included all possible regional voxels. We then vectorized functional connectivity maps across all possible voxels and calculated the connectivity pattern similarity between parents and their children based on the cosine similarity. The cosine similarity is the cosine of the angle formed between two vectors, and the patterns are considered to be more similar if the cosine coefficient is close to 1 (Dimsdale-Zucker and Ranganath, 2018; Lee et al., 2019) (Fig. 1).

In order to confirm that the findings are specific to the connectivity between emotion network and other brain regions in responding to the emotional movie, and not because of general parent–child similarity, we further repeated the analyses with two other types of connectivity. Specifically, we examined how similarly motor network interacts with other brain regions in responding to the emotional movie between parents and children, using a motor network seed obtained from NeuroSynth (2565 studies associated with "motor" term) for the movie watching fMRI data. We also examined how similarly emotion network interacts with other brain regions during resting state between parents and children, using the same emotion network seed for the resting-state data. By comparing the main results with these two controls, we aimed to determine the specificity of our findings and demonstrate that the observed dyadic effects are truly specific to the emotion-related processing in the brain.

Psychological measures

Family cohesion. Family cohesion was assessed using the 10-item Cohesion subscale of the Family Adaptation and Cohesion Evaluation Scales II inventory (Olson et al., 1979). Youth rated how often they felt a certain way or did certain things with the participating parent (i.e., mother or father) on a 5-point Likert scale from 1 (almost never) to 5 (almost always). Example items included "My mother/father and I are supportive of each other during difficult times" and "My mother/father and I like to spend our free time with each other." The item scores were averaged, so that higher mean scores reflected greater family cohesion and relationship closeness with parents ($\alpha = 0.84$).

Youth's negative affect. Youth's negative affect was measured using the 14 negative affect items from the Positive and Negative Affect

Schedule (Crawford and Henry, 2004; Hughes and Kendall, 2009). Youth indicated the extent to which they had felt each of the 14 negative affects (e.g., irritable, afraid, distressed, ashamed) during the past few weeks on a 5-point Likert scale from 1 (slightly/not at all) to 5 (extremely). The mean score of the items was taken with higher values reflecting youth's greater negative affect ($\alpha = 0.90$).

Youth's anxiety. Youth's anxiety was assessed using the Revised Children's Manifest Anxiety Scale (Reynolds and Richmond, 1978). For 25 items, youth rated how often they had the feelings described by each item in the past week (e.g., "I got nervous when things did not go the right way" and "It was hard for me to get to sleep at night") on a 5-point Likert scale ranging from 0 (never) to 4 (very often). The item scores were averaged with higher mean scores indicating youth's greater anxiety ($\alpha = 0.93$).

Youth's ego resilience. Youth's ego resilience was measured using the 6-item Brief Resilience Scale (B. W. Smith et al., 2008). Youth responded to each item (e.g., "I tend to bounce back quickly after hard times" and "I usually come through difficult times with little trouble") on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The item scores were averaged, so that higher mean scores indicated youth's greater ego resilience and ability to bounce back from stress ($\alpha = 0.87$).

Analytic plan

Descriptive statistics of the sample and psychological variables were performed before the primary analyses (Table 1). To examine the hypotheses, two sets of general linear regression models were conducted with 5000 bootstrapping resampling at a 95% confidence interval (CI). The first set of analyses examined how parent–child similarity in the connectivity between emotion network and other brain regions during movie viewing is related to youth's emotional adjustment. Specifically, youth's negative affect, anxiety, and ego resilience were predicted by parent–child movie-evoked neural similarity of emotion network seed-based connectivity in three separate models. The second set of analyses investigated the moderating role of family cohesion in the links between parent–child neural similarity and youth's emotional adjustment. Three moderation models were tested with youth's negative affect, anxiety, and ego resilience as the outcome variable, respectively. Simple slope analyses were then used to probe all significant interaction effects.

In addition, to control for the possible confounding effects of participants' demographic characteristics, we reran all models after adjusting for parents' age, parents' biological sex (0 = male, 1 = female), parents' educational attainment (0 = less than bachelor's degree, 1 = bachelor's degree or above), youth's age, youth's biological sex (0 = male, 1 = female), youth's race/ethnicity (0 = non-Hispanic White, 1 = racial/ethnic minority), and psychotropic medications (0 = neither the parent nor the child was taking psychotropic medications, 1 = the parent or the child was taking psychotropic medications) as covariates. There was one child who was taking psychotropic medications in our sample. After excluding this parent–child dyad, all results remained the same patterns using the remaining 31 parent–child dyads. Finally, to ensure the results were specific to parent–child neural similarity in the connectivity between emotion network and other brain regions during movie viewing, we reperformed the two sets of analyses to examine the connectivity between motor network and other brain regions during movie viewing and the connectivity between emotion network and other brain regions during resting state. All analyses were performed using SPSS 25.0.

Results

Parent–child neural similarity and youth's emotional adjustment

The first set of analyses was to examine whether parent–child similarity in the functional connectivity between emotion network and other brain regions during movie viewing was associated with youth's emotional adjustment, including negative affect, anxiety, and ego resilience. Results showed marginally significant associations between parent–child connectivity pattern neural similarity and youth's negative affect as well as anxiety. That is, the greater parent–child dyads exhibited similarity in how emotion network interacts with other brain regions during movie viewing, the less youth showed negative affect ($\beta = -0.34$, $p = 0.06$, model $R^2 = 0.11$) and anxiety ($\beta = -0.35$, $p = 0.05$, model $R^2 = 0.12$). In a similar vein, such heightened parent–child neural similarity during movie viewing was related to youth's greater ego resilience ($\beta = 0.46$, $p = 0.008$, model $R^2 = 0.21$).

As shown in Table 2, the associations remained the same after adjusting for parents' age, biological sex, educational attainment, youth's age, biological sex, race/ethnicity, and parent or child psychotropic medications (for negative affect, $\beta = -0.37$, $p = 0.04$, model $R^2 = 0.35$; for anxiety, $\beta = -0.33$, $p = 0.08$, model $R^2 = 0.28$; for ego resilience, $\beta = 0.41$, $p = 0.03$, model $R^2 = 0.33$). In contrast, parent–child similarity in how motor network interacts with other brain regions during movie viewing or how emotion network interacts with other brain regions during resting state was not related to youth's emotional adjustment outcomes, with or without the demographic covariates (p values > 0.26).

Table 1. Sample descriptive information[a]

Variables	Parent–child dyads (N = 32) Mean	SD	Range
Parents' age	43.53	7.30	30-64
Parent's biological sex	0.72	0.46	0, 1
Parents' education	0.75	0.44	0, 1
Youth's age	11.69	2.80	8-17
Youth's biological sex	0.41	0.50	0, 1
Youth's race/ethnicity	0.31	0.47	0, 1
Psychotropic medications	0.03	0.18	0, 1
Youth's negative affect	2.21	0.74	1-3.71
Youth's anxiety	1.37	0.66	0.24-3.04
Youth's ego resilience	3.21	0.75	1.83-5
Family cohesion	3.58	0.68	1.70-5

[a]Parents' and youth's biological sex was coded as 0 (male) and 1 (female). Parents' education was coded as 0 (less than bachelor's degree) and 1 (bachelor's degree or above). Youth's race/ethnicity was coded as 0 (non-Hispanic White) and 1 (racial/ethnic minority). Psychotropic medications were coded as (0 = neither the parent nor the child was taking psychotropic medications, 1 = the parent or the child was taking psychotropic medications).

The moderating role of family cohesion

The second set of analyses was to investigate whether the link between parent–child movie-evoked neural similarity of emotion network seed-based connectivity and youth's emotional adjustment may vary among families with higher versus lower levels of cohesion. Results revealed that family cohesion significantly moderated the effects of such parent–child neural similarity on youth's negative affect ($\beta = -0.43$, $p = 0.01$, model $R^2 = 0.35$), anxiety ($\beta = -0.43$, $p = 0.02$, model $R^2 = 0.31$), and ego resilience ($\beta = 0.36$, $p = 0.03$, model $R^2 = 0.37$). Simple slope analyses were further conducted to examine the associations between parent–child neural similarity and the three emotional adjustment outcomes for youth who reported high (i.e., 1 SD above the mean) versus low (i.e., 1 SD below the mean) levels of family cohesion. As shown in Figures 2 and 3, for youth who reported high levels of family cohesion, greater parent–child similarity in how emotion network interacts with other brain regions during movie viewing was associated with youth's lower negative affect (standardized simple slope = −0.14, $p = 0.002$), less anxiety (standardized simple slope = −0.17, $p = 0.002$), and higher ego resilience (standardized simple slope = 0.15, $p = 0.03$). However, for youth who reported low levels of family cohesion, such parent–child neural similarity was not associated with youth's negative affect (standardized simple slope = 0.05, $p = 0.30$), anxiety (standardized

Table 2. Main and interaction effects of parent–child neural connectivity pattern similarity and family cohesion on youth's emotional adjustment[a]

	Negative affect						Anxiety						Ego resilience					
	Main effect model			Interaction effect model			Main effect model			Interaction effect model			Main effect model			Interaction effect model		
	B	SE	β	B	SE	β	B	SE	β	B	SE	β	B	SE	β	B	SE	β
Intercept	2.83	0.92		3.25	0.93		2.45	0.86		2.62	0.84		2.58	0.95		2.24	0.94	
Parent–child neural similarity	−2.00	0.95	−0.37*	−1.38	0.90	−0.25	−1.60	0.88	−0.33†	−1.06	0.81	−0.22	2.26	0.98	0.41*	1.63	0.91	0.30†
Family cohesion	—	—	—	−0.29	0.26	−0.27	—	—	—	−0.08	0.23	−0.09	—	—	—	0.25	0.26	0.23
Parent–child neural similarity × family cohesion	—	—	—	−3.59	1.71	−0.36*	—	—	—	−4.31	1.54	−0.49*	—	—	—	4.05	1.74	0.41*
Covariates																		
Parent's age	−0.02	0.02	−0.15	−0.02	0.02	−0.18	−0.03	0.02	−0.29	−0.03	0.02	−0.31	0.01	0.02	0.09	0.01	0.02	0.12
Parent's biological sex	0.33	0.31	0.20	0.25	0.29	0.16	0.01	0.29	0.01	−0.10	0.26	−0.07	0.10	0.32	0.06	0.19	0.29	0.12
Parent's education	−0.14	0.31	−0.08	−0.20	0.29	−0.12	−0.19	0.29	−0.13	−0.31	0.26	−0.21	−0.29	0.32	−0.17	−0.21	0.30	−0.12
Youth's age	−0.01	0.05	−0.04	−0.04	0.06	−0.14	0.01	0.05	0.05	0.01	0.05	0.05	0.02	0.06	0.09	0.04	0.06	0.16
Youth's biological sex	0.54	0.28	0.36†	0.40	0.26	0.27	0.29	0.26	0.22	0.14	0.24	0.11	−0.04	0.29	−0.02	0.12	0.27	0.08
Youth's race/ethnicity	−0.03	0.28	−0.02	−0.09	0.27	−0.06	0.32	0.26	0.22	0.34	0.25	0.24	−0.51	0.29	−0.32†	−0.26	0.28	−0.29†
Psychotropic medications	1.62	0.89	0.39†	0.62	0.84	0.15	0.57	0.74	0.15	−0.23	0.76	−0.06	−0.40	0.82	−0.10	0.61	0.86	0.14
R^2	0.35			0.51			0.28			0.49			0.33			0.50		

[a]Parents' and youth's biological sex was coded as 0 (male) and 1 (female). Parents' education was coded as 0 (less than bachelor's degree) and 1 (bachelor's degree or above). Youth's race/ethnicity was coded as 0 (non-Hispanic White) and 1 (racial/ethnic minority). Psychotropic medications were coded as (0 = neither the parent nor the child was taking psychotropic medications, 1 = the parent or the child was taking psychotropic medications).
$*p < 0.05$. $^{\dagger}p < 0.10$.

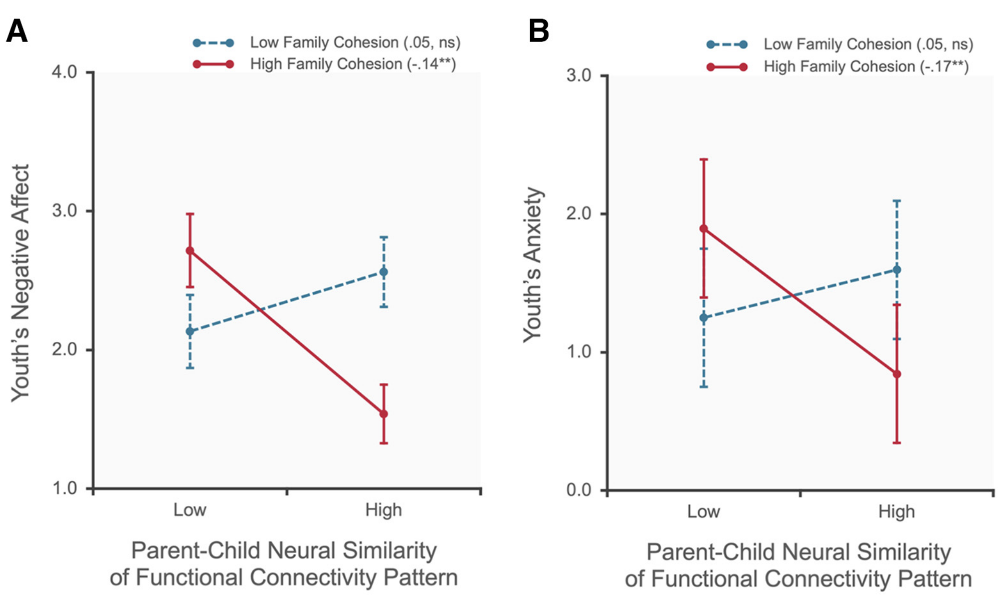

Figure 2. The association between parent–child movie-evoked neural similarity of emotion network seed-based connectivity and youth's negative affect (***A***) and anxiety (***B***) was moderated by family cohesion. High (or low) parent–child neural similarity/family cohesion is 1 SD above (or below) the mean of parent–child neural similarity/family cohesion. Error bars indicate the 95% CI of the estimation. Standardized simple slopes are shown in parentheses. $**p < 0.01$. ns = not significant.

simple slope = 0.05, $p = 0.35$), or ego resilience (standardized simple slope = –0.01, $p = 0.85$).

Again, as shown in Table 2, the moderation effects remained significant when analyses controlled for the demographic covariates (i.e., parents' age, biological sex, educational attainment, youth's age, biological sex, race/ethnicity, and parent or child psychotropic medications; for negative affect, $\beta = -0.36$, $p = 0.04$, model $R^2 = 0.51$; for anxiety, $\beta = -0.49$, $p = 0.01$, model $R^2 = 0.49$; for ego resilience, $\beta = 0.41$, $p = 0.03$, model $R^2 = 0.50$). In addition, family cohesion did not moderate the relations between parent–child similarity in how motor network interacts with other brain regions during movie viewing or how emotion network interacts with other brain regions during resting state and youth's emotional adjustment, regardless of controlling for the demographic covariates or not (p values > 0.15).

Discussion

Children and their parents are naturally inclined to connect and be attuned to each other (Ainsworth et al., 2015; Bell, 2020). The similarity developed within the parent–child dyads at behavioral, psychological, and neurobiological levels has important implications for children to thrive in the complex and rapidly changing world (Hove and Risen, 2009; Wheatley et al., 2012). Despite an increasing body of research on parent–child similarity at the neural level (e.g., Lee et al., 2017c; Ratliff et al., 2022; Turk et al., 2022), little is known about how it may contribute to children's

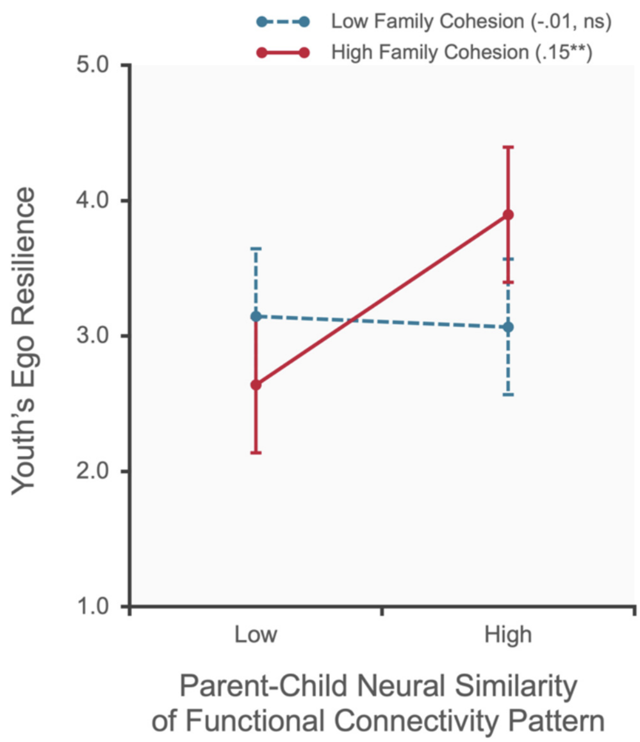

Figure 3. The association between parent–child movie-evoked neural similarity of emotion network seed-based connectivity and youth's ego resilience was moderated by family cohesion. High (or low) parent–child neural similarity/family cohesion is 1 SD above (or below) the mean of parent–child neural similarity/family cohesion. Error bars indicate the 95% CI of the estimation. Standardized simple slopes are shown in parentheses. $^{**}p < 0.01$. ns = not significant.

emotional adjustment. Using a naturalistic movie-watching fMRI paradigm and the functional connectivity pattern similarity analysis with the emotion network seed, this study found that greater parent–child similarity in how emotion network interacts with other brain regions during movie viewing was associated with children's better emotional adjustment, including less negative affect, lower anxiety, and greater ego resilience to bounce back from adversities. Our findings also provide the first empirical evidence that the beneficial role of parent–child neural similarity may depend on family contexts. Specifically, family cohesion moderated the links between parent–child neural similarity and children's emotional adjustment.

Compared with the functional connectivity during resting state or highly controlled experimental tasks, the naturalistic movie-watching design allows us to effectively trigger rich brain activities in a more ecologically valid setting and explore how emotion network communicates with other brain regions when parent–child dyads respond to emotionally salient situations (Hasson et al., 2004; Lahnakoski et al., 2014; Finn et al., 2017). Indeed, our results found that the associations between parent–child neural similarity and children's emotional adjustment were only significant for the emotion network seed-based connectivity, but not for the motor network seed-based connectivity during the movie viewing, which highlights that how similarly emotion network (e.g., bilateral amygdala and the right temporal pole) (Yarkoni et al., 2011) interacts with other brain regions in parent–child dyads may play a unique role in promoting children's emotion development. The associations were also not significant for parent–child resting-state connectivity similarity using the emotion network seed, suggesting that how much parents and children show similarities when actively responding to emotionally salient situations may have greater implications for children's emotional adjustment compared with the similarities in their intrinsic neural systems and brain configurations.

Prior research suggests that neural functional connectivity in parent–child dyads may play a role in children's socio-emotional experiences (Lee et al., 2017b). Greater parent–child neural similarity when watching an emotion-engaging movie may indicate that parents and children respond similarly in various emotional situations in daily life, helping them show empathy and understanding to each other in such situations (Nummenmaa et al., 2012). Such emotional concordance between parents and children may not only provide a foundation for shared emotional experiences and the formation of affectionate bonds (Kobak et al., 1993; Feldman, 2007; Stern et al., 2015), but also facilitate parental emotion socialization of their children (Hajal and Paley, 2020; Meng et al., 2020). In addition, parent–child neural similarity may also subserve the dyadic coregulation processes in stressful situations (Quiñones-Camacho et al., 2020, 2021), and consequently foster the adaptive self-regulation of the children and help them build up resilience against stress (Bazhenova et al., 2001; Ratliff et al., 2022). Therefore, parent–child neural similarity may ultimately benefit children's emotional adjustment, as reflected in reducing their risks of experiencing negative affect and anxiety, and promoting their ego resilience in adverse contexts.

Notably, our findings further suggest that the benefits of parent–child neural similarity may vary across different family contexts. Parent–child neural similarity while watching the same movie without face-to-face communication may reflect their abilities to align their thoughts and emotional states with each other with minimal external behavioral cues (Azhari et al., 2019). Although these abilities may be shaped by both genetic factors and earlier life experiences (Reindl et al., 2018; Kim et al., 2022), whether such abilities can ultimately confer benefits to children's emotional adjustment may also depend on their current family environment. Prior research suggested that mutual emotional exchanges provide the ground for parents and their children to share experiences, build attunement, and facilitate socialization (Curci and Rimé, 2012; Ponnet et al., 2013). Therefore, parent–child dyads from families with higher cohesion, which is characterized by supportive and emotional interactions and bonding, may be more likely to develop emotional coordination and adjustment given heightened neural similarities (Anderson and Keltner, 2004). In contrast, children from families with lower cohesion may lack the contexts or opportunities to benefit from such similarities. Our results are in line with prior physiological work suggesting that parent–child physiological similarity may not always be adaptive or promotive, and sometimes may even be maladaptive under certain circumstances (e.g., families with greater cumulative risks) (J. D. Smith et al., 2016; Suveg et al., 2016; Davis et al., 2018; Ratliff et al., 2022). Together, our findings highlight the importance for future research to consider "in what context" parent–child neural similarity may play either a beneficial or detrimental role in children's development.

The current study has some limitations. First, the cross-sectional design with a focus on adolescents does not allow us to examine the developmental trajectories or the directionality of the study variables. Future studies using longitudinal approaches can improve our understanding of how parent–child neural similarity may change over time as well as its long-term influences on children's development. Second, our sample size is relatively small, which may limit the generalizability of our findings and the possibility of conducting additional analyses with subgroups.

For example, although our findings were robust after adjusting for participants' demographic characteristics, such as sex, race/ethnicity, and age, we were not able to fully explore the subgroup differences because of the small sample size. Scholars have highlighted that parent–child neural similarity patterns and their implications for children's adjustment may vary across parent–child dyads with different sex combinations (e.g., mother–daughter, father–son) or different cultural contexts (Chen and Qu, 2021; Ratliff et al., 2021). Similarly, how parent–child relationships and youth's emotion-related brain regions interactively influence youth's emotional development may vary among youth at different stages of adolescence (Laursen and Collins, 2009; Ahmed et al., 2015). Future research should consider the possible differences among specific populations. In addition, future research that can compare biological parent–child dyads and adoptive parent–child dyads may shed light on the investigations in the genetic versus environmental effects for neural similarity. Third, we did not examine parents' emotional well-being, which may be associated with both parent–child neural similarity and youth's emotional adjustment. For example, parent–child neural similarity may serve as a mechanism of how parents' emotional distress and anxiety are transmitted to their children. Future studies may investigate the role that parents' emotional well-being plays in parent–child neural similarity and youth's emotional development. In addition, other possible individual or contextual factors (e.g., family socioeconomic status, parenting style, presence of psychopathology) that may modulate the relations between parent–child neural similarity and children's adjustment are also worth further investigation. Fourth, prior work exploring the potential differences in neural similarity between different types of dyads found that only parent–child dyads, but not stranger-child dyads, showed brain-to-brain synchrony during cooperative interactions (Reindl et al., 2018). Future research may examine whether the findings in the current study are specific to parent–child dyads or can be generalized to other types of dyads. Lastly, future studies may use other experimental paradigms, tasks, neuroimaging methods, and statistical modeling approach to examine the generalizability of our findings. For example, hyperscanning of parents and children using fNIRS or EEG during active social interactions can examine whether the current findings can be applied to the real-time parent–child neural synchrony during interactions, which may demand fine-tuned communicative rhythms in more systems (e.g., sensory and motor system) between the dyads (Fishburn et al., 2018; Bizzego et al., 2022). Also, future studies may consider examining directional relationship (e.g., dynamic causal modeling), rather than functional connectivity, to explore the possible causal effects between the brain regions (Stephan and Friston, 2010).

In conclusion, this study provides new evidence that parent–child neural similarity may confer benefits to children's emotional adjustment, and highlights the unique role of naturally activated emotion-related network in this process by using a seed-based functional connectivity analysis. Most importantly, we identified the moderating role of family cohesion and found that children living in more positive family environments may be more likely to derive benefits from their neural similarity with their parents. To our knowledge, this is the first empirical evidence showing that the associations between parent–child neural similarity and children's development may depend on family contexts. These findings have important contributions to the literature by increasing our understanding of the neurobiological mechanisms regarding how children thrive by establishing attunement with their primary caregivers, and highlighting the importance of investigating these processes by taking contextual factors into consideration.

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