Altered Functional Connectivity Patterns Associated with Perceived Discrimination in Adolescents

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Abstract

Perceived discrimination is a pervasive social stressor with significant implications for adolescent mental health and neurodevelopment. Using resting-state functional magnetic resonance imaging (rs-fMRI) data from the Adolescent Brain Cognitive Development (ABCD) Study, we investigated the relationship between perceived discrimination and functional connectivity patterns in the adolescent brain. We applied a Network-Based Statistic (NBS) analysis to 268x268 connectome data from 5,084 participants who provided data on perceived discrimination. Perceived discrimination was coded as a binary variable (Yes/No) based on participants' responses to a validated discrimination scale. Our analysis identified two primary subnetworks associated with perceived discrimination: a positive subnetwork, characterized by increased connectivity between the right prefrontal cortex, left insula, and subcortical regions, and a negative subnetwork, marked by disrupted connectivity between the right prefrontal cortex and left temporal regions. The positive subnetwork suggests enhanced cross-hemispheric communication in adolescents reporting discrimination, while the negative subnetwork indicates reduced cross-hemispheric integration in those reporting no discrimination. Additionally, significant alterations in connectivity across large-scale brain networks were observed. Specifically, adolescents reporting discrimination exhibited increased connectivity between visual processing networks and regions involved in attentional control, while showing decreased connectivity in other network interactions. These findings offer novel insights into the neural mechanisms underlying the effects of perceived discrimination on adolescent brain function, particularly in regions related to emotion regulation, social cognition, and stress responses. Our results underscore the importance of considering discriminatory experiences in the context of adolescent neurodevelopment and mental health.

Background

Perceived discrimination, particularly based on race or ethnicity, is a pervasive social issue with significant implications for mental health and cognitive development, especially among adolescents.[1,2] Recent studies have highlighted the detrimental effects of perceived discrimination on various aspects of adolescent well-being, including increased stress, anxiety, and depression.[3,4] The adolescent brain undergoes significant structural and functional changes, making it particularly vulnerable to the effects of chronic stressors such as discrimination.[5,6] Neuroimaging studies have begun to elucidate the neural correlates of perceived discrimination, suggesting alterations in brain regions involved in emotion regulation, social cognition, and stress response.[7,8]

Resting-state functional magnetic resonance imaging (rs-fMRI) has emerged as a powerful tool for investigating intrinsic brain connectivity patterns associated with various psychological and social phenomena.[9] This technique allows researchers to examine functional connectivity between different brain regions in the absence of specific task demands, providing insights into the brain's baseline functioning.[10] Previous research has identified alterations in functional connectivity associated with experiences of social exclusion and rejection, which share some similarities with perceived discrimination.[11-13] However, the specific neural mechanisms underlying the perception and processing of discrimination, particularly in adolescents, remain poorly understood.

The Adolescent Brain Cognitive Development (ABCD) Study provides a unique opportunity to investigate these questions on a large scale, offering a diverse sample of adolescents and comprehensive neuroimaging data.[14] Prior work by Nagata et al (2021) and Fields et al. (2024) have established a framework for assessing perceived discrimination within the ABCD cohort, paving the way for more detailed neuroimaging analyses.[15,16]

Network-based approaches, such as the Network-Based Statistic (NBS) method, have shown promise in identifying subnetworks of brain regions that exhibit altered connectivity in various psychiatric and neurological conditions.[17] Applying these techniques to the study of perceived discrimination may reveal novel insights into the neural substrates of this important social phenomenon.

The present study aims to address this gap in the literature by examining the association between perceived discrimination and resting-state functional connectivity patterns in a large sample of adolescents from the ABCD Study. By leveraging advanced neuroimaging techniques and network analysis methods, we seek to identify specific brain networks that may be altered in adolescents who report experiences of discrimination, potentially shedding light on the neural mechanisms underlying the impact of discrimination on adolescent brain function and development.

Methods

Participants

Data were drawn from the 5.1 release of the Adolescent Brain Cognitive Development (ABCD) Study, which includes a diverse sample of 11,868 children aged 9-10 years at baseline, recruited from 22 sites across the United States. For this analysis, we included participants who had complete resting-state fMRI (rs-fMRI) data and valid responses to the perceived discrimination questionnaire. Participants with excessive head motion (framewise displacement > 0.2 mm) during the fMRI scan were excluded. The final sample consisted of 5,084 participants (after exclusions for motion).

Perceived Discrimination Measure

Perceived discrimination was measured using eight questions adapted from the Perceived Discrimination Scale, following the approach from prior research.[15] These questions assessed experiences of unfair treatment based on race, ethnicity, or color, and participants' responses were used to codify perceived discrimination as a binary outcome (Yes/No).

The questions were part of follow-up assessment at ages 10-11, asking participants to reflect on their experiences over the past 12 months. The first question was:

1. In the past 12 months, have you felt discriminated against because of your race, ethnicity, or color?
    - Responses of "Yes" were categorized as perceived discrimination.

For the following seven questions, participants were asked how often they had experienced various forms of discrimination from different sources, rated on a 5-point Likert scale (1 = Almost Never, 5 = Very Often). Responses of 3 (Sometimes), 4 (Often), or 5 (Very Often) were categorized as "Yes" for perceived discrimination. The questions were:

2. How often do teachers treat you unfairly or negatively because of your ethnic background?
3. How often do other adults outside school treat you unfairly or negatively because of your ethnic background?
4. How often do other students treat you unfairly or negatively because of your ethnic background?
5. I feel that others behave in an unfair or negative way toward my ethnic group.
6. I feel that I am not wanted in American society because of my ethnic background.
7. I don't feel accepted by other Americans because of my ethnic background.
8. I feel that other Americans have something against me because of my ethnic background.

Participants who responded affirmatively (i.e., "Yes" to Question 1 or 3–5 on any of Questions 2–8) were categorized as having experienced perceived discrimination. Those who responded "No" to Question 1 or chose "1" or "2" for all other questions were categorized as not perceiving discrimination ("No"). Null or non-responsive answers across all eight questions resulted in exclusion from the analysis. This binary outcome was used as the primary measure in all analyses of perceived discrimination.

Resting-State fMRI Data Acquisition and Preprocessing

Resting-state fMRI data were collected using a 3T MRI scanner at each site. The scanning parameters included an echo-planar imaging (EPI) sequence with the following parameters: repetition time (TR) = 800 ms, echo time (TE) = 30 ms, flip angle = 52 degrees, and voxel size = 2.4 x 2.4 x 2.4 mm. Data were preprocessed following the ABCD study pipeline, including slice-timing correction, motion correction, spatial normalization to MNI space, and smoothing with a 6-mm Gaussian kernel. Framewise displacement was calculated to identify and exclude participants with excessive head motion (threshold > 0.2 mm). The functional data were then parcellated using the Shen 268-node atlas, which provides 268 regions of interest (ROIs) for connectivity analysis.[18]

Functional Connectivity Analysis

Functional connectivity was computed as the Pearson correlation coefficient between the time series of each pair of the 268 ROIs, resulting in a 268x268 functional connectivity matrix for each participant. These matrices were Fisher Z-transformed for normalization before further analysis.

Network-Based Statistic (NBS) Analysis

We applied the Network-Based Statistic (NBS) approach to identify significant differences in functional connectivity between participants who reported perceived discrimination (Yes) and those who did not (No). The NBS is a method for identifying clusters of connections (subnetworks) that exhibit significant group differences while controlling for the family-wise error rate across the entire brain network. For this analysis, we used a primary threshold of $p < 0.001$ to identify individual connections (edges) that significantly differed between the groups. Permutation testing (5,000 permutations) was conducted to control for multiple comparisons, and subnetworks were considered significant if the family-wise error (FWE) corrected p-value was below 0.05.

Statistical Analysis

Statistical analyses were conducted using R (v4.3.2) and MATLAB (v2023b). Logistic regression models were used to assess the relationship between functional connectivity and perceived discrimination, adjusting for potential confounders such as age, gender, race/ethnicity, parental education, and household income. NBS was performed using the **nbs** package in Python, and visualization of the network map was generated using BioImageSuite.[19]

Ethical Considerations

The ABCD Study and this analysis were approved by the local Institutional Review Boards (IRBs) at participating institutions. Informed consent was obtained from parents or legal guardians, and assent was provided by participants before data collection. All study procedures were conducted in accordance with the Declaration of Helsinki.

Results

In the current study, we conducted a whole-brain Network-Based Statistic (NBS) analysis using resting-state fMRI (rs-fMRI) 268x268 connectome data to predict perceived discrimination across participants. Perceived discrimination was codified as a binary outcome (Yes/No) following the methods used in prior research (Fields et al., 2024).[15] The dataset included all subjects who reported perceived discrimination and had available rs-fMRI data that were not excluded for excessive head motion (threshold of framewise displacement >0.2mm).

Figure 1 presents a network map of the significant subnetworks identified by the NBS analysis. This map highlights several key inter-lobar connections across multiple brain regions, showing altered connectivity associated with perceived discrimination, along with significant laterality effects. Figure 1 primarily provides insight into the regional connections between brain areas, illustrating specific alterations in inter- and intra-lobar connectivity.

The NBS analysis identified two primary subnetworks (one positive, one negative) associated with perceived discrimination. The positive subnetwork, indicated by red connections in the network map, primarily involves inter-lobar connections between the right prefrontal cortex, left insula, and left subcortical regions (e.g., the limbic system). Notably, the right prefrontal cortex showed consistent positive connections across all left-lobe regions (insula, parietal, occipital, and temporal lobes), suggesting increased cross-hemispheric communication in participants reporting discrimination.

In contrast, the negative subnetwork, shown by blue connections, involved disrupted connectivity between the right prefrontal cortex and several left hemisphere regions, particularly the left temporal and left prefrontal lobes. This suggests that participants who did not report perceived discrimination exhibited reduced functional connectivity between these regions, reflecting potentially decreased cross-hemispheric integration.

Additionally, within the left hemisphere, both positive and negative intralobar connections were identified, particularly across the prefrontal, parietal, and temporal regions. These left-lobe intralobar connections indicate more complex, localized network alterations associated with perceived discrimination, hinting at differential processing or integration within these regions.

In total, the NBS analysis revealed a significant positive component ($p < 0.05$, family-wise error corrected) involving 72 edges, primarily linking the right prefrontal and left subcortical and temporal regions. A separate significant negative component ($p < 0.05$) involved 58 edges, indicating disrupted connections across the left temporal and occipital lobes, as well as reduced right-to-left prefrontal connectivity.

Figure 2 provides additional insights, focusing on the connectivity between major brain networks (e.g., the default mode network, salience network, and visual networks), rather than specific regional connections. Figure 2a shows positive increases in connectivity between networks in participants reporting perceived discrimination compared to those not reporting discrimination, while Figure 2b illustrates decreased connectivity between networks in participants reporting discrimination versus those not reporting discrimination. In Figure 2a, a strong positive correlation is observed between the VII (visual network) and VAs (visual association area), indicating enhanced visual processing and integration in participants reporting discrimination. In contrast, Figure 2b shows reduced connectivity between these regions in participants reporting discrimination, suggesting potential alterations in visual-spatial processing and attentional control. Additionally, Figure 2a highlights increased connectivity between the visual networks and other large-scale brain networks, such as the salience (SAL) and default mode network (DMN), in participants reporting discrimination.

These results suggest that perceived discrimination is associated with alterations in both regional and large-scale network connectivity. The findings from Figure 1 highlight disruptions in inter- and intra-lobar functional connectivity, particularly in prefrontal regions, while Figure 2 reveals changes in connectivity between major brain networks, such as the visual and default mode networks. These alterations have potential implications for emotion regulation, sensory processing, and social cognition. The identified laterality patterns, particularly the asymmetry in prefrontal connectivity, may reflect differential neural mechanisms involved in processing experiences of discrimination.

Discussion

Our study provides novel insights into the neural correlates of perceived discrimination in adolescents, revealing significant alterations in functional connectivity patterns associated with this pervasive social stressor. By leveraging data from the Adolescent Brain Cognitive Development (ABCD) Study—a large, diverse, and longitudinal cohort—this research extends previous work on the neural correlates of social exclusion and rejection[11-13] by specifically focusing on perceived discrimination. The use of resting-state fMRI data from the ABCD cohort provides valuable insights into the intrinsic brain organization associated with discrimination experiences, complementing previous task-based studies in this area.

The Network-Based Statistic (NBS) analysis identified two primary subnetworks—one positive and one negative—that differentiate adolescents reporting perceived discrimination from those who do not. These findings underscore the unique neural adaptations associated with discrimination, particularly in large-scale brain networks involved in emotion regulation and social cognition. The positive subnetwork, characterized by increased connectivity primarily between the right prefrontal cortex and left subcortical and temporal regions, suggests enhanced cross-hemispheric communication in adolescents experiencing discrimination. This finding aligns with previous research indicating heightened prefrontal activation during social exclusion tasks.[11,12,20-22] The involvement of subcortical regions, particularly the limbic system, in this network may reflect increased emotional processing and stress responses associated with discriminatory experiences.[7] Conversely, the negative subnetwork, showing disrupted connectivity between the right prefrontal cortex and left temporal and prefrontal regions, may indicate altered cognitive control and emotional regulation processes in adolescents not reporting discrimination. This pattern of reduced cross-hemispheric integration could represent a more efficient or specialized neural organization in these individuals.[23]

The observed laterality effects, particularly the asymmetry in prefrontal connectivity, are intriguing and warrant further investigation. Lateralized brain function has been implicated in various aspects of emotion processing and social cognition.[24] Our findings suggest that experiences of discrimination may be associated with distinct patterns of hemispheric integration, potentially reflecting differential strategies for processing and coping with these experiences.

The involvement of the insula in the positive subnetwork is particularly noteworthy, given its role in interoception and social cognition.[25] Increased connectivity between the insula and prefrontal regions may reflect heightened awareness of bodily states and emotions in response to discriminatory experiences, consistent with theories of embodied cognition in social processing.[26]

Our findings also demonstrate the impacts of discrimination on visual processing and its integration with other brain networks. The observed increased connectivity between visual networks (VII and VAs) in participants reporting discrimination suggests enhanced visual processing and integration. This alteration could reflect heightened vigilance or increased attention to visual cues in the environment, potentially as a adaptive response to experiences of discrimination.

The increased connectivity between visual networks and other large-scale brain networks, such as the salience network (SAL) and default mode network (DMN), in participants reporting discrimination is particularly intriguing. This pattern might indicate a more integrated processing of visual information with networks involved in detecting salient stimuli (SAL) and self-referential thinking (DMN). Such integration could reflect a neural mechanism for heightened awareness and processing of potentially discriminatory visual cues in one's environment.

Interestingly, these findings align with recent research on altered visual processing in trauma-exposed populations, particularly in Black individuals with PTSD. Harnett and colleagues (2022) found that Black American women with PTSD exhibited increased connectivity between visual and salience networks compared to trauma-exposed controls.[27-29] The authors suggested that this hyperconnectivity might represent a neural correlate of hypervigilance, a common symptom in PTSD that involves heightened sensitivity to potential threats in the environment. Our findings of increased visual network connectivity in adolescents reporting perceived discrimination parallel these results, suggesting that experiences of discrimination might lead to similar neural adaptations as those seen in trauma exposure. Furthermore, the reduced connectivity between visual networks observed in Figure 2b for participants reporting discrimination could indicate a more complex reorganization of visual processing. This might reflect a trade-off between enhanced integration of certain visual pathways and reduced connectivity in others, possibly as a means of optimizing attention to relevant social cues while filtering out less pertinent visual information. They suggest that the neural impact of discrimination extends beyond regions traditionally associated with emotion and social cognition to include fundamental sensory processing networks. This broader impact underscores the pervasive nature of discrimination's effects on brain function and highlights the need for comprehensive approaches in studying and addressing the neural correlates of discriminatory experiences.

Our study has several strengths, including its large sample size, the use of advanced network analysis techniques, and the focus on a critical developmental period. However, some limitations should be noted. First, the cross-sectional nature of the data precludes causal inferences about the relationship between perceived discrimination and brain connectivity. Longitudinal studies are needed to elucidate the directionality of these associations and to examine how discrimination-related brain changes may evolve over time. Second, while we controlled for several potential confounding factors, unmeasured variables may still influence the observed relationships. Future studies should consider additional factors such as family environment, peer relationships, and specific types of discriminatory experiences. Third, the binary categorization of perceived discrimination, while based on established methods,[15] may not capture the full complexity of discriminatory experiences. Future research could benefit from more nuanced measures of discrimination, including frequency, severity, and specific domains of discrimination. Despite these limitations, our findings have important implications for understanding the neurodevelopmental impact of perceived discrimination. The altered connectivity patterns we observed may represent neural markers of discrimination-related stress, potentially contributing to the well-documented negative health outcomes associated with discrimination.

From a clinical perspective, these results highlight the importance of considering discriminatory experiences in assessments of adolescent mental health and well-being. Interventions aimed at reducing the impact of discrimination may need to consider its effects on brain function and connectivity. Additionally, our findings could inform the development of neuroimaging-based markers for assessing the efficacy of anti-discrimination interventions.

Future research should further explore the functional significance of these visual network alterations, perhaps through task-based fMRI studies that directly assess visual processing of socially relevant stimuli in individuals with varying levels of perceived discrimination. Additionally, longitudinal analysis within the ABCD dataset will help elucidate whether these changes in visual network connectivity are a cause or consequence of perceived discrimination, and how they might relate to long-term psychological and health outcomes.

In conclusion, this study provides evidence for altered functional brain connectivity associated with perceived discrimination in adolescents. The identified subnetworks implicate regions involved in emotion regulation, social cognition, and stress responses, offering new insights into the neural mechanisms underlying the impact of discrimination on adolescent brain function. Future research should build on these findings to further elucidate the complex relationships between discriminatory experiences, brain development, and long-term health outcomes in diverse populations.

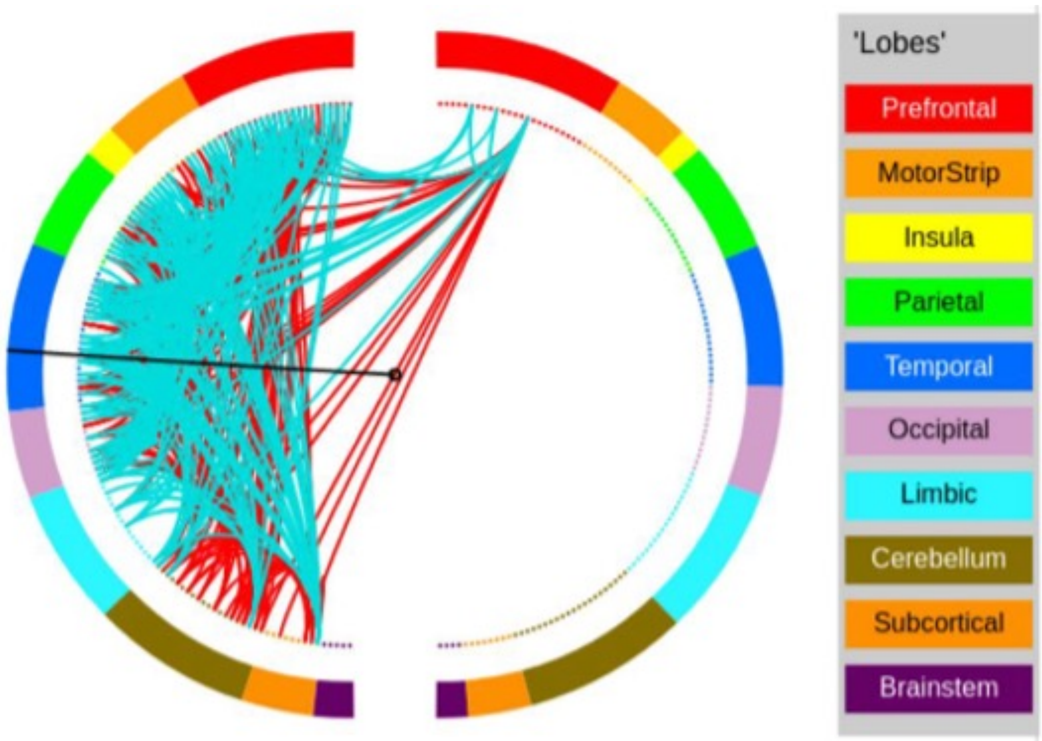
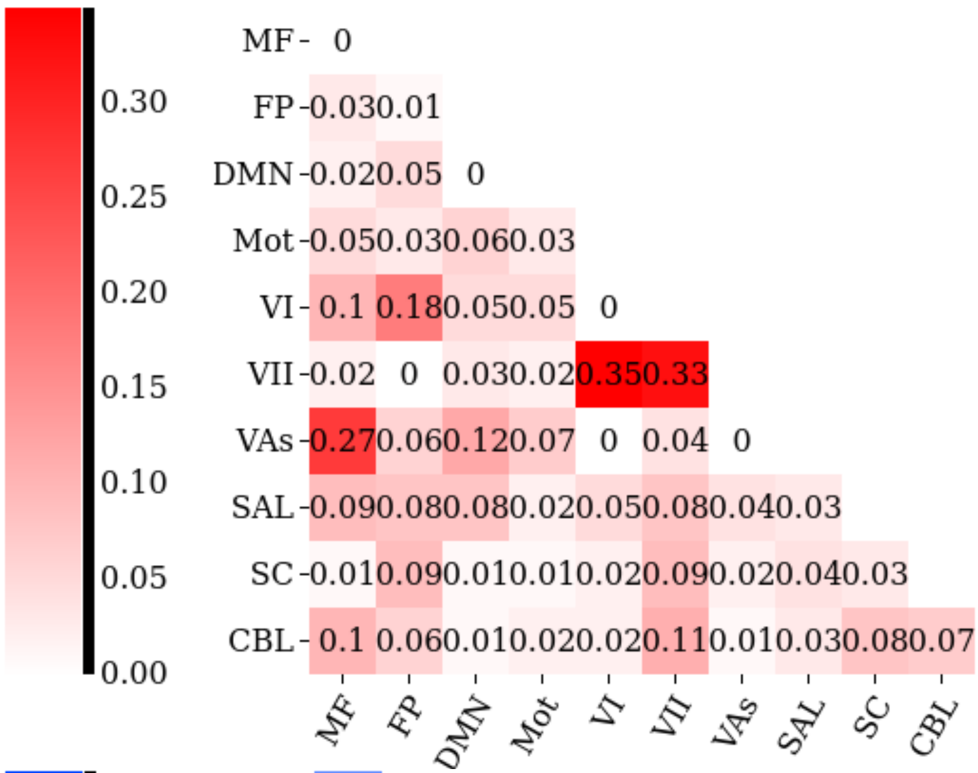


Figure 1. *Whole-brain network map revealing significant components associated with perceived discrimination.* The network map visualizes significant subnetworks identified by the Network-Based Statistic (NBS) analysis using 268x268 rs-fMRI connectivity data. The outer rings represent different brain lobes, color-coded as follows: Prefrontal (red), MotorStrip (orange), Insula (yellow), Parietal (green), Temporal (blue), Occipital (purple), Limbic (cyan), Cerebellum (brown), Subcortical (tan), and Brainstem (dark red). Red lines indicate edges in the positive subnetwork, representing increased connectivity primarily between the prefrontal cortex, insula, and subcortical regions, associated with participants who reported experiencing perceived discrimination. Blue lines represent edges in the negative subnetwork, indicating decreased connectivity between temporal, occipital, and parietal regions, primarily seen in participants who did not report perceived discrimination. The analysis included participants with available rs-fMRI data who were not excluded due to excessive head motion, and perceived discrimination was codified as a binary outcome (Yes/No). The positive and negative subnetworks were significant at $p < 0.05$, corrected for multiple comparisons using family-wise error (FWE). This figure illustrates the differential brain network patterns linked to experiences of discrimination, suggesting functional connectivity alterations in regions related to emotion, social cognition, and sensory processing.



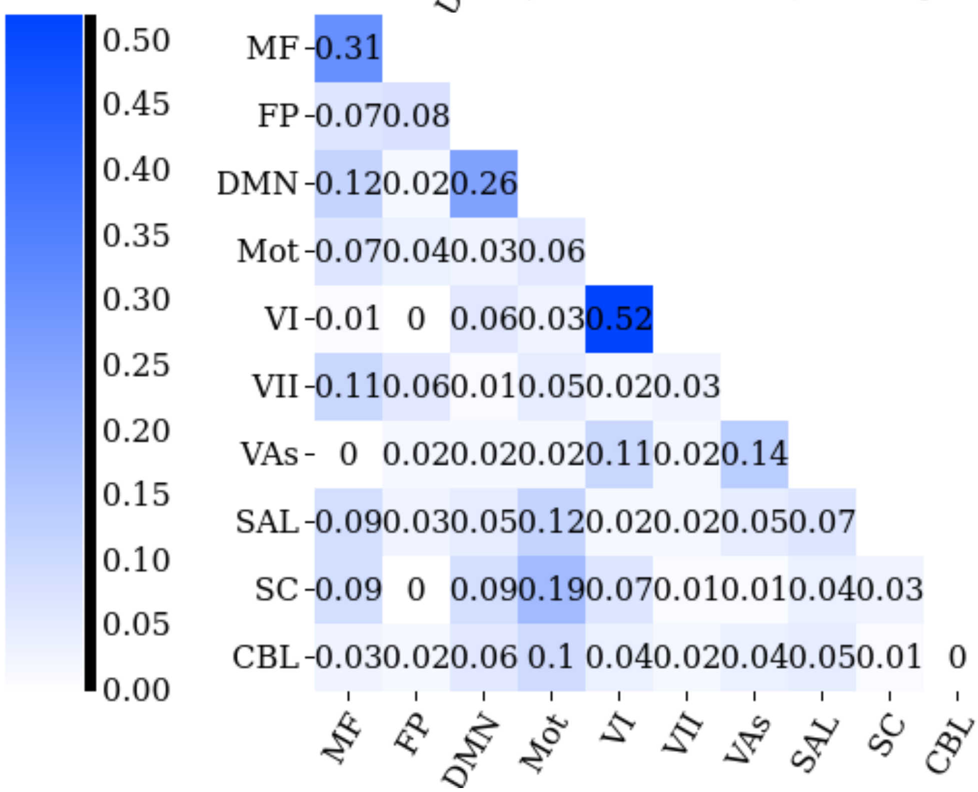


Figure 2. *Functional connectivity between large-scale brain networks in adolescents reporting perceived discrimination versus those not reporting discrimination.*

Figure 2a and Figure 2b display the functional connectivity between large-scale brain networks in adolescents who reported perceived discrimination compared to those who did not. The numbers in each cell of the heatmap represent the correlation coefficients between pairs of brain networks, calculated using Pearson correlation to assess the strength of connectivity between regions. Positive values in Figure 2a (red) indicate increased connectivity between networks in participants reporting discrimination, while negative values in Figure 2b (blue) indicate decreased connectivity in these participants. For example, in Figure 2a, the correlation between the visual network VII and the visual association area (VAs) is 0.35, suggesting stronger integration between these networks in adolescents reporting discrimination. In contrast, Figure 2b shows a correlation of -0.11 between the same networks, indicating reduced connectivity in participants who reported discrimination. These heatmaps provide insights into the functional relationships between large-scale brain networks, such as the default mode network (DMN), salience network (SAL), visual networks (VI, VII), and motor network (Mot), across the two groups. The statistical analyses involved calculating correlation coefficients for each pair of brain networks, followed by group comparisons between participants who reported discrimination and those who did not. The heatmaps illustrate the magnitude of connectivity differences, providing a clear visual representation of how perceived discrimination is associated with both increases and decreases in large-scale network connectivity. These results suggest that discrimination experiences may influence network-level integration, with potential implications for sensory processing, emotion regulation, and attentional control in adolescents.

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Author Contributions:

- **Christopher Fields**: Conceptualization, data analysis, drafting of the manuscript, and interpretation of results.
- **Raimundo Rodriguez**: Data preprocessing, methodology, and revisions to the manuscript.
- **Matthew Rosenblatt**: Statistical analysis, data interpretation, and revisions to the manuscript.
- **Dustin Scheinost**: Supervision, guidance on fMRI analysis, and critical review of the manuscript.

Data Availability: The data supporting the findings of this study were obtained from the Adolescent Brain Cognitive Development (ABCD) Study. Due to restrictions, the data are available upon reasonable request from the corresponding author or from the ABCD Study Data Access portal. The source data used in this study were openly available prior to its initiation. The ABCD data used in this report came from the fast track data release 5.1, which is accessible to qualified researchers through the NIMH Data Archive (NDA). The raw data are available at https://nda.nih.gov/study.html?id=2313, and the data dictionary for ABCD can be found at https://data-dict.abcdstudy.org/. Additional details about the measures assessed for the ABCD study are provided at https://wiki.abcdstudy.org/release-notes/start-page.html. Instructions for obtaining NDA data use certification are available at https://nda.nih.gov/nda/access-data-info.

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