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Parental Education and Functional Connectivity between Nucleus Accumbens (NAcc) and Frontoparietal Network (FPN)

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Abstract

Introduction: While previous studies have indicated an association between socioeconomic status (SES) and children’s neuroimaging measures, weaker SES effects are shown for Black than White families. This is, in part, due to processes such as stratification, racism, marginalization, and othering of Black people in the US, which act as barriers to translating SES resources into health outcomes. Purpose: This study had two aims: First, to test the association between parental education and the nucleus accumbens (NAcc) resting-state functional connectivity (rsFC) with the frontoparietal network (FPN) in children; and second, to investigate racial heterogeneity in this association. Methods: This cross-sectional study used data from the Adolescent Brain Cognitive Development (ABCD) study. We analyzed the resting-state functional connectivity data of 7959 US pre-adolescents who were between 9 and 10 years old. The main outcome was the NAcc resting-state functional connectivity with FPN. Parental education was considered as an independent variable. Family structure, sex and age were the study covariates. Finally, race was regarded as the moderator. We used mixed-effects regression for data analysis with and without interaction terms between parental education and race. Results: Parental education was associated with higher NAcc resting-state functional connectivity with FPN. Race showed a statistically significant interaction with parental education, suggesting that the effects of parental education on NAcc rsFC with FPN was significantly weaker for Black pre-adolescents compared to White pre-adolescents. Conclusions: In line with Minorities’ Diminished Returns (MDRs), the association between parental education and pre-adolescents’ NAcc rsFC with FPN is weaker in Black pre-adolescents compared to their White counterparts. This finding is of interest because FPN’s rsFC with NAcc may have a role in
cognitive flexibility and reward processing. The weaker links between SES indicators and children’s neuroimaging findings for Black than for White families may reflect the racialization of Blacks in the US. Social stratification, racism, and discrimination may minimize the returns of SES in Black communities.

Keywords
socioeconomic status, parental education, brain development, pre-adolescents, MRI, functional MRI, functional connectivity

1. Introduction
The Nucleus Accumbens (NAcc), a subcortical brain structure located within the ventral striatum serving as a key limbic-motor interface, holds an important role in Pavlovian learning (Ferrario, 2020; Stelly, Girven, Lefner, Fonzi, & Wanat, 2021). This means that the NAcc regulates emotional and motivation processing (Salgado & Kaplitt, 2015), incentive salience (Olney, Warlow, Naffziger, & Berridge, 2018), and pleasure, reward, and reinforcement (Boissonneault, Stennett, & Robinson, 2020). In addition, neural reactivity to food- and/or drug-related reward cues could evoke robust dopamine responses in the NAcc (Stelly et al., 2021). As such, the NAcc is a part of the brain reward system, reflecting how an individual responds to cues that signal a potential reward (Stelly et al., 2021). Because the NAcc has various functions, it is unsurprising that the NAcc has been implicated in several psychological disorders and conditions impacting health, such as obsessive-compulsive disorder (Chen et al., 2021; Zhang et al., 2020), anxiety (Zhang et al., 2020), depression (Heshmati et al., 2020), obesity (Ferrario, 2020; Rapuano et al., 2020), food addiction (Domingo-Rodriguez et al., 2020), tobacco abuse, and alcohol and drug-seeking behaviors (Boissonneault, Lewis, & Nixon, 2019; Buck, Torregrossa, Logan, & Freyberg, 2021; Sousa et al., 2020). As a result, NAcc receives projections from a number of large-scale brain networks to have been able to fulfill its functions, such as the frontoparietal network (FPN), salience network (SN), and the default mode network (DMN) (Cerit et al., 2019; Cooper & Knutson, 2008; Ding et al., 2020).

Neuroimaging studies have revealed some alterations between NAcc and FPN functional connectivity (Cerit et al., 2019). The FPN, also known as the central executive network (CEN), is a large-scale brain networks that works with the basal ganglia, striatum, and NAcc (Tan et al., 2015). The FPN has long been implicated in cognitive control (Cai, Griffiths, Korgaonkar, Williams, & Menon, 2019), attention (Markett et al., 2014), problem-solving (Markett et al., 2014), working memory (Markett et al., 2014), attention deficit/hyperactivity disorder (ADHD) (Cai et al., 2019; Gao et al., 2019), cocaine addiction (Barrós-Loscertales et al., 2020) and various mental disorders (Lees et al., 2021) in preadolescence. Similarly, McTeague et al. indicated a pattern of disruption in the FPN during cognitive control tasks among patients with various disorders, including schizophrenia, bipolar or unipolar depression, anxiety, and substance use disorders (McTeague et al., 2017).

The highly sophisticated use of functional magnetic resonance imaging (fMRI) has enabled scientist to examine brain regions and networks. fMRI is a widely used measurement of resting-state functional connectivity (rsFC). rsFC is established to investigate the temporal correlation of spatially distributed
brain regions activity at the resting state when the participant yet not engage in an explicit task (S. M. Smith et al., 2009). Comparing against the rsFC allows us to identify spontaneous brain activity patterns that contribute to give insight into neural activity patterns (Hohenfeld, Werner, & Reetz, 2018). Furthermore, rsFC is used to explore networks not easily assessed during task activities. Finally, it tends to be free from a bias in task selection and also derive benefit from relatively easy data collection (Hohenfeld et al., 2018).

Via frontoparietal-accumbal connectivity, the FPN and NAcc joint function have some role in motivated behavior, food seeking, emotion regulation, food preference, obesity, eating disorders, and reward systems of the brain including dopaminergic rewards (Cerit et al., 2019; Ding et al., 2020; Kim et al., 2019; Ma et al., 2010). In a cross-sectional study of 51 subjects, Liu et al. found a decreased rsFC between the NAcc and the FPN regions in patients who have major depressive disorder (MDD) (Liu et al., 2021). Likewise, Smith et al. found significantly stronger connectivity between the FPN and the left and right nucleus accumbens in physician assistant students and residents having received mindfulness training (J. L. Smith et al., 2021). Also, in a longitudinal study of 69 Mexican-origin adolescents aged 10 to 16 years, Weissman et al. found that years of substance use was associated with increased connectivity between the right NAcc and the FPN, which is central to cognitive control (Weissman et al., 2015).

In comparison to peers with high socioeconomic status (SES), children from low SES families seem to disproportionately have worse outcomes across several areas (Jenkins et al., 2020). These include cognitive development (McDermott et al., 2019), language (Noble et al., 2015), executive function (Noble et al., 2015), and school achievement (McDermott et al., 2019). Pre-adolescents with lower SES also experience higher rates of some mental and physical health problems and risk behaviors (McDermott et al., 2019), including anxiety and depression (Merz, Tottenham, & Noble, 2018), alcohol problems (Barr, Silberg, Dick, & Maes, 2018), smoking (Hiscock, Dobbie, & Bauld, 2015; Martinez et al., 2018), early initiation of sexual behavior (Valencia, Tran, Lim, Choi, & Oh, 2019), delinquency (Rekker et al., 2015), obesity (Shaikh, Siahpush, Singh, & Tibbits, 2015), high blood pressure (Kaczmarek, Stawińska-Witoszyńska, Krzyżaniak, Krzywińska-Wiewiorowska, & Siwińska, 2015).

Parental education is considered as a key SES indicator, which seem to affect brain structures and function. A wide range of brain structures, including thalamus (Shervin Assari & Curry, 2021), hippocampus (Shervin Assari, Shanika Boyce, Mohsen Bazargan, & Cleopatra H Caldwell, 2020b), amygdala (Merz et al., 2018), and nucleus accumbens (Shervin Assari, 2020c) are shown to be linked to parental education. Moreover, parental education can be linked to antisocial behaviors (Piotrowska, Stride, Croft, & Rowe, 2015), externalizing problems (Bøe, Øverland, Lundervold, & Hysing, 2012), anxiety and depression (Merz et al., 2018), behavioral problems (Hosokawa & Katsura, 2018), psychiatric disorders (Hosokawa & Katsura, 2018), mental health problems (Reiss, 2013) tobacco dependence and aggression (Shervin Assari, Caldwell, & Bazargan, 2019) and mathematics and problem-solving achievement (Long & Pang, 2016) in children and adolescents.

According to the Minorities’ Diminished Returns (MDRs), most SES indicators, especially parental
education, produce unequal outcomes for population subgroups (Shervin Assari, 2020b, 2021a). The MDRs theory postulates that racial minority children are less likely to have equal opportunity to gain from their parental education benefits to ensure health outcomes, due to discrimination, stratification, racialization, and social marginalization (Shervin Assari, Boyce, Akhlaghipour, Bazargan, & Caldwell, 2020; Chetty, Hendren, Kline, & Saez, 2014). This means that the social structure continues to decrease parental education’ effects on developmental outcomes for racial minority more than majority groups (Shervin Assari, 2020d, 2021b). As a result, children born to racial minority, regardless of how highly educated their parents may be, experience greater risk for poor health outcomes (Shervin Assari & Curry, 2021). Thereby, some studies have shown systematically weaker effects of parental education on a wide range of health outcomes for children of marginalized groups (Shervin Assari, 2018a, 2018b). As an example, Black children indicate weaker effects of parental education on attention (Shervin Assari, Boyce, & Bazargan, 2020), school performance (Spera, Wentzel, & Matto, 2009), reward dependence (Shervin Assari, Akhlaghipour, Boyce, Bazargan, & Caldwell, 2020), impulsivity (Morris, Silk, Steinberg, Myers, & Robinson, 2007), suicide (Shervin Assari, Shanika Boyce, Mohsen Bazargan, & Cleopatra H. Caldwell, 2020a), aggression (Pabayo, Molnar, & Kawachi, 2014), depression (S. Assari, Caldwell, & Mincy, 2018) and problem behaviors (Shervin Assari, Boyce, Caldwell, & Bazargan, 2020) compared to White children.

Previous neuroimaging studies on MDRs have evaluated the association between household income on children’s brain structure (Assari, 2021b; Assari et al., 2018). Different than income and poverty, parental education tend to represent an aspect of SES which is not represented by the presence of financial or material resources in the family (Mackey et al., 2015). However, there is still a lack of studies on the association of parental education with the brain rsFC of the NAcc and FPN by race. Likewise, it is necessary to examine the connectivity between the FPN and brain structures such as NAcc, as they present cross-system measures and are engaged in more advanced brain function (Karcher, O’Brien, Kandala, & Barch, 2019). NAcc-FPN connectivity seems to represent some of the more advanced brain functions, namely social, emotional, behavioral or executive function skill development (Rakesh, Zalesky, & Whittle, 2021; Su, Li, Zhou, & Shu, 2021). NAcc rsFC with FPN appears to associate with cognition, behaviors, emotions, and psychological problems (Karcher et al., 2019; Rakesh et al., 2021). Given how many vital brain functions NAcc-FPN connectivity seems to be associated in, studying how parental education affects this connectivity, and how race moderates this relationship is necessary.

**Aims**

The present study aimed to first investigate the correlation between parental education and rsFC between NAcc and FPN and second to examine racial heterogeneity in this correlation in a sample of 9/10-year-old pre-adolescents from the Adolescent Brain Cognitive Development research (ABCD) study (Casey et al., 2018; Karcher et al., 2019). We hypothesized that parental education would be positively associated with the rsFC of NAcc and FPN, and also there were weaker effects of parental education on NAcc rsFC with FPN for Black pre-adolescents in comparison with White pre-adolescents.
2. Methods

Design and Settings
Data for this secondary cross-sectional research were from the Adolescent Brain Cognitive Development (ABCD) study, a trailblazing study of children’s brain development (Karcher et al., 2019; Research & Staff, 2018). The ABCD study has a diverse sample in terms of SES, sex, race, and ethnicity (Auchter et al., 2018). Here is some information in regard to ABCD samples, methods, measures, and imaging techniques (Auchter et al., 2018).

Participants and Sampling
The ABCD study is a multi-site longitudinal study which has recruited children aged 9 to 10 years from 21 multiple cities across different states to characterize their psychological and neurobiological development from early adolescence to early adulthood (Casey et al., 2018). The participants were recruited through schools across the 21 study sites (Garavan et al., 2018). The ABCD study is not a nationally representative sample of adolescents despite its careful sampling (Garavan et al., 2018). However, the ABCD sample is still a near approximation of the U.S. children regarding to age, SES, ethnicity, sex, and urbanicity (Garavan et al., 2018). Children were included into this secondary analysis regardless of their race, ethnicity and psychopathology (Garavan et al., 2018).

Process (Brain Imaging)
Resting-state functional MRI was used to calculate rsFC between NAcc and FPN in preadolescents. Three, 3 tesla (T) scanner platforms were used to collect fMRI data, including Philips Healthcare, GE Healthcare, and Siemens Healthcare, in the ABCD study (Hagler Jr et al., 2019). T1-weighted and T2-weighted brain images were taken from the MRI equipment (Casey et al., 2018). Because of variation in imaging sites, T1-weighted and T2-weighted images were corrected for gradient magnetic field nonlinearity distortions to decrease bias (Jovicich et al., 2006). For maximizing mutual information’s relative position and orientation, pre-processed structural data were calculated based on T1- and T2-weighted images (Wells III, Viola, Atsumi, Nakajima, & Kikinis, 1996). The ABCD study used intensity non-uniformity correction with tissue segmentation and sparse spatial smoothing. Further, images have been resampled with 1-mm isotropic voxels into rigid alignment within the brain atlas. These volumetric measures were constructed with FreeSurfer software, version 5.3.0 (Harvard University). Images also have undergone surface optimization (Fischl & Dale, 2000; Fischl, Sereno, & Dale, 1999) and nonlinear registration to a spherical surface-based atlas (Fischl et al., 1999).

Study Variables
The study variables included parental education (independent variable), children’s race (moderator), ethnicity, age, sex, parental marital status (confounders), and NAcc rsFC with the FPN (dependent variable).

Independent Variable
Parental Education. Parental education was considered as a five-level nominal variable: less than high school (HS) diploma, high school (HS) diploma, some college, bachelors’ degree, and post graduate
degree.

**Dependent Variables**

NAcc rsFC with FPN. Using resting-state fMRI, NAcc rsFC with FPN was defined as the average correlation between the FPN and ASEG ROI right-accumbens area. The rsFC between the FPN and the NAcc was measured at baseline at the same time that parental education was measured. Our outcome had a normal distribution (**Appendix Figure**).

**Moderators**

**Race.** Race was reported by the parent and was considered as a moderator. Race was treated as a nominal variable: Black, Asian, Other/Mixed, and White (reference group).

**Confounders**

**Age.** It was treated as a continuous variable, which was reported by the parents as months.

**Sex.** It was considered as a categorical variable with 0 for girls and 1 for boys.

**Ethnicity.** It was treated as a dichotomous variable coded as Latino = 1 and non-Latino = 0

**Parental Marital Status.** It was also a dichotomous variable, self-reported by the parent interviewed, and coded 1 vs. 0 for married and unmarried or other condition.

**Data Analysis**

We used the Data Exploration and Analysis Portal (DEAP), a user-friendly online platform for multivariable analysis of the ABCD data, for our data analysis. For multivariable analyses, two mixed-effects regression models were estimated. **Model 1** tested the additive effects of parental education, race, and covariates, without interaction terms. **Model 2** also included interaction terms between parental education and race on rsFC between NAcc and FPN. Moreover, we checked the normal distribution of our outcome (**Appendix**). In all models, NAcc rsFC with FPN was the outcome. Also, mixed-effects regression coefficients (b), standard errors (SE), and p-values were reported.

**Ethical Aspect**

The original ABCD research protocol received Institutional Review Board (IRB) approval in several institutions, including the University of California, San Diego (UCSD). Additionally, we received the ABCD data through an agreement between Charles R. Drew University and NIH/NDA. As the ABCD data were fully de-identified, our study was seen as non-human subject research, thus was exempted from a full review. All children also provided verbal assent to the protocol approved by the IRB and all caregivers or parents signed the written informed consent form (Auchter et al., 2018).

3. Results

**Sample Descriptive Data**

The present study used data from a large sample of 7959 pre-adolescents between 9 and 10 years of age ($M_{\text{Age}} = 119.47$ months, $SD = 7.53$). From the pooled sample, 3989 were female. The study contained 5373 White, 1084 Black, 176 Asian American, and 1326 other/mixed race children. Participants included 6387 non-Latino children. Black participants showed the lowest parental education and White and Asian
children showed the highest parental education. Furthermore, rsFC of NAcc with FPN was significantly different across racial groups. Sample demographic and descriptive statistics are shown in Table 1.

Table 1. Descriptive Characteristics Overall and by Race (n =7959)

| Level                  | Overall | All   | White | Black | Asian | Other/Mixed | p   |
|------------------------|---------|-------|-------|-------|-------|-------------|-----|
| N                      | 7959    | 5373  | 1084  | 176   | 1326  |             |     |
| **Mean(SD)**           |         |       |       |       |       |             |     |
| Age (Months)           | 119.47 (7.53) | 119.55 (7.54) | 119.33 (7.28) | 119.85 (7.98) | 119.23 (7.63) | 0.430 |
| Neighborhood SES       | 20.31 (15.61) | 16.77 (12.70) | 34.60 (18.90) | 14.94 (12.91) | 23.68 (16.20) | <0.001 |
| Right NAcc functional connectivity with the FPN | -0.01 (0.12) | 0.00 (0.11) | -0.02 (0.14) | -0.02 (0.12) | -0.01 (0.13) | <0.001 |
| Left NAcc functional connectivity with the FPN | -0.06 (0.14) | -0.06 (0.13) | -0.04 (0.16) | -0.07 (0.14) | -0.05 (0.14) | <0.001 |
| Parental Education     |         |       |       |       |       |             |     |
| < HS Diploma           | 302 (3.8) | 133 (2.5) | 81 (7.5) | 5 (2.8) | 83 (6.3) | <0.001 |
| HS                     | 649 (8.2) | 258 (4.8) | 240 (22.1) | 2 (1.1) | 149 (11.2) |     |
| Diploma/GED            |         |       |       |       |       |             |     |
| Some College           | 2023 (25.4) | 1113 (20.7) | 447 (41.2) | 14 (8.0) | 449 (33.9) |     |
| Bachelor               | 2108 (26.5) | 1606 (29.9) | 156 (14.4) | 44 (25.0) | 302 (22.8) |     |
| Post Graduate Degree   | 2877 (36.1) | 2263 (42.1) | 160 (14.8) | 111 (63.1) | 343 (25.9) |     |
| Hispanic Ethnicity     |         |       |       |       |       |             |     |
| No                     | 6387 (80.2) | 4416 (82.2) | 1027 (94.7) | 159 (90.3) | 785 (59.2) | <0.001 |
| Yes                    | 1572 (19.8) | 957 (17.8) | 57 (5.3) | 17 (9.7) | 541 (40.8) |     |
| Married Family         |         |       |       |       |       |             |     |
| No                     | 2348 (29.5) | 1075 (20.0) | 750 (69.2) | 26 (14.8) | 497 (37.5) | <0.001 |
| Yes                    | 5611 (70.5) | 4298 (80.0) | 334 (30.8) | 150 (85.2) | 829 (62.5) |     |
| Sex                    |         |       |       |       |       |             |     |
| F                      | 3989 (50.1) | 2632 (49.0) | 577 (53.2) | 108 (61.4) | 672 (50.7) | 0.001 |
| M                      | 3970 (49.9) | 2741 (51.0) | 507 (46.8) | 68 (38.6) | 654 (49.3) |     |

Notes: Source: Adolescent Brain Cognitive Development (ABCD) Study; * Chi-square test; ** Analysis of Variance (ANOVA)

The mixed effects regression model is summarized in Table 2. Models with the interaction effect showed a better fit when compared to main effect, reflecting that interaction between parental education and race contribute to the outcome.
Table 2. Effect Sizes and % Variance Explained

|          | Right |          | Left |          |          |
|----------|-------|----------|------|----------|----------|
| N        | 7959  | 7959     | 7959 | 7959     |
| R-squared| 0.007 | 0.008    | 0.005| 0.006    |
| ΔR-squared| 0.001| 0.004    | 0.0007| 0.004   |
| ΔR-squared (%) | 0.17  | 0.45     | 0.08 | 0.43     |

Main Effects
As shown by Table 3, Figure 1 and Figure 3, parental education showed a positive association with the functional connectivity between the FPN and the right and left NAcc. For the right side, correlations were significant for bachelor \((b = 0.022; p = 0.005)\) and graduate degree \((b = 0.018; p = 0.022)\). For the left side, some college \((b = 0.019; p = 0.034)\), and graduate degree \((b = 0.015; p = 0.095)\) indicated positive links with the outcome.

Table 3. Mixed-effects Regressions in the Overall Sample

|                                      | Right |          | Left |          |          |
|--------------------------------------|-------|----------|------|----------|----------|
|                                      | b     | SE       | p    | b        | SE       | p        |
| Parental Education (HS Diploma/GED)  | 0.008 | 0.008    | 0.345| 0.009    | 0.010    | 0.378    |
| Parental Education (Some College)    | 0.011 | 0.008    | 0.154| 0.019*   | 0.009    | 0.034    |
| Parental education (Bachelor)        | 0.022**| 0.008| 0.005| 0.013    | 0.009    | 0.142    |
| Parental education (Graduate Degree) | 0.018*| 0.008    | 0.022| 0.015#   | 0.009    | 0.095    |
| Race (Black)                         | -0.010*| 0.005| 0.030| 0.019***| 0.005    | 0.001    |
| Race (Asian)                         | -0.020*| 0.009| 0.030| -0.008  | 0.011    | 0.436    |
| Race (Other/Mixed)                   | -0.002| 0.004    | 0.595| 0.011*   | 0.004    | 0.016    |
| Hispanic                             | -0.004| 0.004    | 0.377| -0.001  | 0.005    | 0.784    |
| Married Family                       | 0.004 | 0.003    | 0.262| -0.002  | 0.004    | 0.539    |
| Sex                                  | 0.003 | 0.003    | 0.331| 0.010**  | 0.003    | 0.001    |
| Age                                  | 0.000 | 0.000    | 0.108| 0.000    | 0.000    | 0.317    |
| Neighborhood SES                     | 0.000 | 0.000    | 0.168| 0.000    | 0.000    | 0.276    |

Outcome: functional connectivity between the frontoparietal network and the NAcc. #p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001
Interactive Effects

Table 4 and Figure 2 showed that parental education had a negative interaction with race on the functional connectivity between the FPN and the right NAcc. This negative interaction was indicative of a weaker positive association between parental education and the FPN-NAcc resting-state functional connectivity in Black children than White children. For the right side, we observed significant interactions between race (Black) and high school diploma/GED ($b = -0.050, p = 0.012$), some college and Black ($b = -0.039, p = 0.034$), and post graduate degree ($b = -0.044, p = 0.026$). However, there were no interactions between parental education and race on left NAcc functional connectivity with the FPN. These suggest that the gain in terms of larger functional connectivity between the FPN and the NAcc as a result of an increase in parental education is diminished for Black children than White children, however, only for the right not left NAcc (Figure 2).

Table 4. Mixed Effects Regressions on the Effects of Parental Education and Race on the Functional Connectivity between the Frontoparietal Network and Nucleus Accumbens

|                                | Right          |                  |                  | Left         |                  |                  |
|--------------------------------|----------------|-----------------|-----------------|--------------|-----------------|-----------------|
|                                | b   | SE  | p    | b   | SE  | p    |
| Parental Education (HS Diploma/GED) | 0.029* | 0.013 | 0.022 | -0.004 | 0.015 | 0.763 |
| Parental Education (Some College) | 0.022* | 0.011 | 0.046 | 0.009 | 0.013 | 0.507 |
| Parental education (Bachelor)    | 0.033** | 0.011 | 0.003 | 0.003 | 0.013 | 0.789 |
| Parental education (Graduate Degree) | 0.030** | 0.011 | 0.008 | 0.002 | 0.013 | 0.890 |
| Race (Black)                    | 0.027 | 0.017 | 0.121 | -0.012 | 0.020 | 0.558 |
| Race (Asian)                    | 0.027 | 0.054 | 0.617 | -0.032 | 0.062 | 0.601 |
| Race (Other/Mixed)              | -0.002 | 0.017 | 0.919 | 0.001 | 0.019 | 0.951 |
| Hispanic                        | -0.003 | 0.004 | 0.511 | -0.002 | 0.005 | 0.612 |
| Married Family                  | 0.004 | 0.003 | 0.240 | -0.003 | 0.004 | 0.479 |
| Sex                             | 0.003 | 0.003 | 0.335 | 0.010** | 0.003 | 0.001 |
| Age                             | 0.000 | 0.000 | 0.108 | 0.000 | 0.000 | 0.373 |
| Neighborhood SES                | 0.000 | 0.000 | 0.183 | 0.000 | 0.000 | 0.233 |
| Parental Education (HS Diploma/GED) × Race (Black) | -0.050* | 0.020 | 0.012 | 0.033 | 0.023 | 0.148 |
| Parental Education (Some College) × Race (Black) | -0.039* | 0.018 | 0.034 | 0.024 | 0.021 | 0.252 |
| Parental Education (Bachelor) × Race (Black) | -0.032 | 0.020 | 0.103 | 0.036 | 0.023 | 0.112 |
| Parental Education (Post Graduate Degree) × Race (Black) | -0.044* | 0.020 | 0.026 | 0.044# | 0.023 | 0.054 |
| Parental Education (HS Diploma/GED) × Race (Asian) | -0.126 | 0.099 | 0.205 | -0.125 | 0.115 | 0.274 |
| Parental Education (Some College) × Race (Asian) | -0.049 | 0.062 | 0.434 | 0.005 | 0.072 | 0.940 |
| Parental Education (Bachelor) × Race (Asian) | -0.043 | 0.057 | 0.447 | 0.027 | 0.065 | 0.675 |
| Parental Education (Post Graduate Degree) × Race (Asian) | -0.048 | 0.055 | 0.378 | 0.030 | 0.063 | 0.639 |
|                                        |     |     |     |     |     |
|----------------------------------------|-----|-----|-----|-----|-----|
| Parental Education (HS Diploma/GED) x Race (Other/Mixed) | -0.022 | 0.021 | 0.275 | 0.014 | 0.024 | 0.567 |
| Parental Education (Some College) x Race (Other/Mixed) | 0.000 | 0.018 | 0.980 | 0.010 | 0.021 | 0.631 |
| Parental Education (Bachelor) x Race (Other/Mixed) | 0.000 | 0.018 | 0.994 | -0.004 | 0.021 | 0.857 |
| Parental Education (Post Graduate Degree) x Race (Other/Mixed) | 0.005 | 0.018 | 0.768 | 0.019 | 0.021 | 0.357 |

Notes: Source: ABCD Study; Mixed-effects regression model is used; 
#p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001

Figure 1. Association between Parental Education and Functional Connectivity between the Right NAcc and FPN Overall

Figure 2. Association between Parental Education and Functional Connectivity between the Right NAcc and FPN by Race

Figure 3. Association between Parental Education and Functional Connectivity between the Left NAcc and FPN Overall
Figure 4. Association between Parental Education and Functional Connectivity between the Left NAcc and FPN by Race

4. Discussion

This study revealed two findings. First, we found a positive correlation between parental education and the NAcc resting-state functional connectivity with the FPN. Second, there were racial disparities in the correlation between parental education and the resting-state FPN’s functional connectivity with the right NAcc. In line with the MDRs theory, the association between parental education and the right NAcc resting-state functional connectivity with FPN was weaker for Black than for White children.

Our first finding is consistent with other work showing the effects of parental education on brain structure and function (Noble et al., 2015) which predict several domains of cognition (Lawson et al., 2014) and emotion (Merz et al., 2018). However, most of the previous neuroimaging studies have been carried out on specific brain regions (Lawson et al., 2017; Leijser, Siddiqi, & Miller, 2018), and SES has been mainly represented by family income (Mackey et al., 2015). Parental education also has an impact on the size and activity of brain structures, such as hippocampus (Shervin Assari, Boyce, Bazargan, et al., 2020b), NAcc (Shervin Assari, 2020c), amygdala (Merz et al., 2018), thalamus (Shervin Assari & Curry, 2021). Examining a sample of 283 children and adolescents aged 4-18 years, Lawson et al. found that higher parental education significantly predicted greater cortical thickness in the right anterior cingulate and left superior frontal gyrus (Lawson, Duda, Avants, Wu, & Farah, 2013). In the ABCD study, Rakesh et al. found that parental education was associated with reduced within and between sensorimotor network connectivity, and increased sensorimotor network connectivity to frontal functional networks (Rakesh et al., 2021).

In line with our first finding, higher parental education is shown to be linked to the development of frontoparietal connectivity in children (Rakesh et al., 2021). Specifically, these neurodevelopmental correlates of parental education appear to mediate why parental education influences vocabulary and language skills (Richels, Johnson, Walden, & Conture, 2013), executive functions (Noble et al., 2015), reading ability (Van Houdt, van Wassenaer-Leemhuis, Oosterlaan, van Kaam, & Aarnoudse-Moens, 2019), spatial skills (Noble, 2015 #2884) and inhibitory control (Shervin Assari, 2020d). Importantly...
however, no studies to our knowledge have examined the associations between parental education and rsFC within the NAcc and FPN.

There are some explanations for our first observation (Duncan & Magnuson, 2012). Parental education may be related to cognitive stimulation available at home, parent–child interactions, and home learning environment, as evident by parental education acting as a strong predictor of academic performance, particularly literacy development (Duncan & Magnuson, 2012; Noble et al., 2015). More educated parents dedicate more time for their children in the ways that seem to improve their development (Guryan, Hurst, & Kearney, 2008; Kalil, Ryan, & Corey, 2012). More educated parents appear to have higher expectations for their children and provide more stimulating learning materials, use more complex language and speech patterns, and show more engagement in their children’s learning (Davis-Kean, 2005; Kalil et al., 2012). All these changes promote children’s cognitive and brain development (Guryan et al., 2008).

Our second finding is consistent with the MDRs theory that has shown that due to racism, parental education is less protective for Black than White children. Importantly, similar MDRs are reported for attention (Shervin Assari, Boyce, & Bazargan, 2020), reward dependence (Shervin Assari, Akhlaghipour, et al., 2020), school performance (Spera et al., 2009), aggression (Pabayo et al., 2014), impulsivity (Morris et al., 2007), suicide (Shervin Assari, Boyce, Bazargan, et al., 2020a), anxiety (Shervin Assari, Caldwell, & Zimmerman, 2018) and problem behaviors (Shervin Assari, Boyce, Caldwell, et al., 2020) in Black adolescents. While MDRs are commonly recognized in pre-adolescents, they can be tracked back to birth (Shervin Assari & Moghani Lankarani, 2018). In line with our findings, SES and parental education are less likely to lead to equal health outcomes for Blacks and Whites across the life span (Shervin Assari, 2020a).

MDRs theory suggests some policy solutions which can lead the Unites States to decrease racial and ethnic health disparities (Butler & Rodgers, 2019). Most past attempts have focused on reducing the SES gap (Bailey et al., 2017). However, because of MDRs, equalizing SES fails to eliminate health inequalities (Bailey et al., 2017). Conversely, due to the systemic disadvantage of Blacks in turning SES resources to outcomes, which is a result of racism, SES is both a solution and a source of racial disparities (Butler & Rodgers, 2019).

The MDRs theory, consequently, advocates for policies that decrease health disparities by removing structural barriers in the lives of marginalized people (Bailey et al., 2017; Butler & Rodgers, 2019). Moreover, policies are needed in the domains of employment and the labor market, which can help reduce the racial gap in health (Shervin Assari & Bazargan, 2019). Additionally, enforcing existing anti-discrimination laws and penalizing the labor market parties and employers who do not adhere to these laws might help to equalize employment of racial groups. Further, programs can be implemented to ensure racial groups to find better jobs (Shervin Assari & Bazargan, 2019).

In this study and all the MDRs literature, race is considered as a social determinant rather than a biological factor. Differential treatment by society, which is preventable, has resulted in the observed racial differences. Thus, we consider race as a proxy of racism, such as labor market discrimination, low
school quality, segregation, and differential policing, resulting in reducing the effects of parental education, even for more educated people (Herrnstein & Murray, 2010).

As this study showed, parental education and race have multiplicative rather than additive effects on the right NAcc resting-state functional connectivity with FPN. Due to racism, regardless of their SES, Black pre-adolescents remain at risk, while high SES significantly reduces the risk for White pre-adolescents.

5. Limitation
The present study had some limitations. Firstly, a cross-sectional design limits any causal inference of the links between parental education and NAcc functional connectivity with the FPN. Secondly, several SES indicators were not included. Moreover, we did not examine how neighborhood context, stress, and social adversities can explain differential effects of SES by race. Thirdly, this study focused only on Black, White, Asian, and Other/Mixed race families. More studies on other sources of marginalizing identities such as immigration should be carried out in the future.

6. Conclusions
Although high parental education is correlated with greater right and left NAcc resting-state functional connectivity with FPN, this association (for the right side) may be weaker for Black than White pre-adolescents. We attribute such racial variation to racism, social stratification, and segregation that can reduce the benefits of parental education in Black communities. In line with the Marginalization-related Diminished Returns (MDRs) framework, these differences may emerge due to the differences in the living experiences of middle-class Black families compared to their White counterpart.

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https://abcdstudy.org/federal-partners.html. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/consortium_members/. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis or writing of this report. This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH or ABCD consortium investigators. The ABCD data repository grows and changes over time. The ABCD data used in this report came from the ABCD 3.0 data release (DOI: 10.15154/1519007). DOIs can be found at https://nda.nih.gov/study.html?id=901.

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(a) Distribution of parental education
(b) Distribution for the functional connectivity between the right NAcc and frontoparietal network

(c) Distribution for the functional connectivity between the left NAcc and frontoparietal network

(d) Quantiles distribution for the association between parental education and functional connectivity between the right NAcc and frontoparietal network

(e) Quantiles distribution for the association between parental education and functional connectivity between the left NAcc and frontoparietal network
(f) Error terms for the association between parental education and functional connectivity between the right NAcc and frontoparietal network

(g) Error terms for the association between parental education and functional connectivity between the left NAcc and frontoparietal network

Appendix Figure