Original Paper

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.

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 (Boissoneault, 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 (Boissoneault, 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 year, 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

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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.

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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_{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)	Mean(SD)	Mean(SD)	Mean(SD)	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
		n(%)	n(%)	n(%)	n(%)	n(%)	
Parental Education	< HS Diploma	302 (3.8)	133 (2.5)	81 (7.5)	5 (2.8)	83 (6.3)	<0.001
	HS Diploma/GED	649 (8.2)	258 (4.8)	240 (22.1)	2 (1.1)	149 (11.2)	
	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	
	Main Effect	**Interaction Effect**	**Main Effect**	**Interaction Effect**
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) ×Race (Other/Mixed)	-0.022	0.021	0.275	0.014	0.024	0.567
Parental Education (Some College) ×Race (Other/Mixed)	0.000	0.018	0.980	0.010	0.021	0.631
Parental Education (Bachelor) ×Race (Other/Mixed)	0.000	0.018	0.994	-0.004	0.021	0.857
Parental Education (Post Graduate Degree) ×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;

#$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$
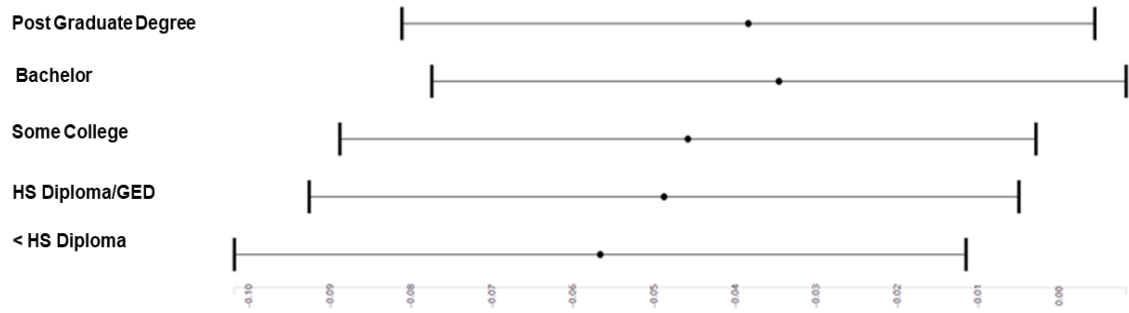
Figure 1. Association between Parental Education and Functional Connectivity between the Right NAcc and FPN Overall
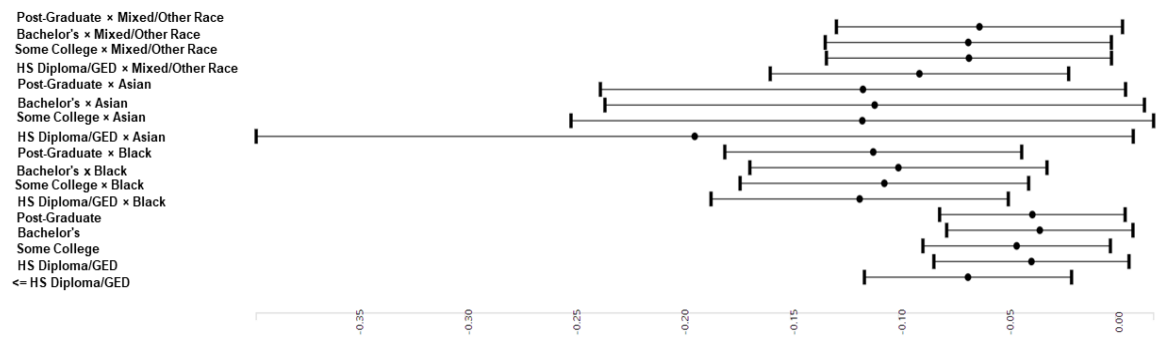
Figure 2. Association between Parental Education and Functional Connectivity between the Right NAcc and FPN by Race
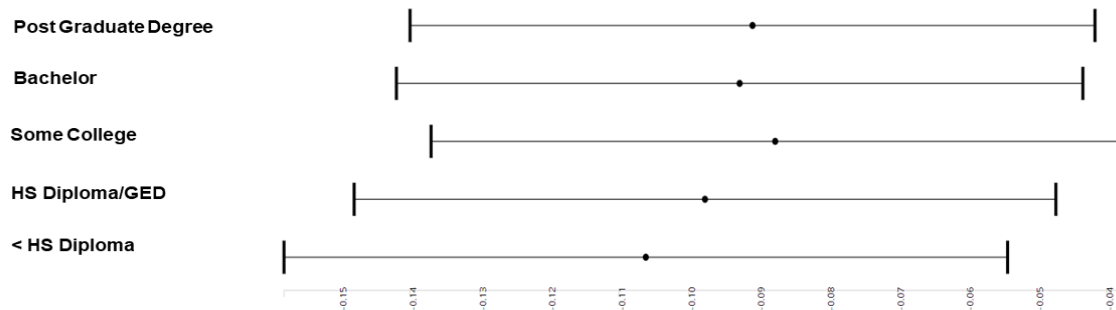
Figure 3. Association between Parental Education and Functional Connectivity between the Left NAcc and FPN Overall

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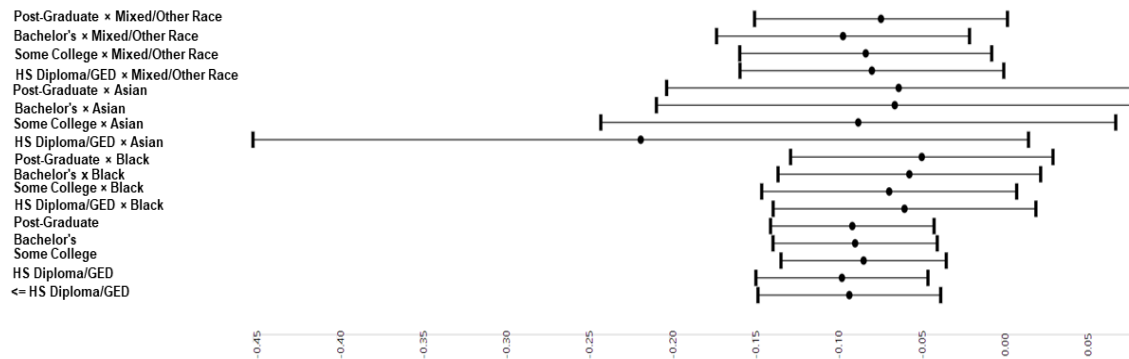
Figure 4. Association between Parental Education and Functional Connectivity between the Left NAcc and FPN by Race

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

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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

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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.

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.

References

Assari, S. (2018a). Parental education attainment and educational upward mobility; role of race and gender. *Behavioral Sciences*, *8*(11), 107. https://doi.org/10.3390/bs8110107

Assari, S. (2018b). Parental Education Better Helps White than Black Families Escape Poverty: National Survey of Children's Health. *Economies*, *6*(2), 30. Retrieved from http://www.mdpi.com/2227-7099/6/2/30

Assari, S. (2020a). College graduation and wealth accumulation: Blacks' diminished returns. *World journal of educational research (Los Angeles, Calif.)*, *7*(3), 1.

Assari, S. (2020b). Mental Rotation in American Children: Diminished Returns of Parental Education in Black Families. *Pediatric Reports*, *12*(3), 130-141. https://doi.org/10.3390/pediatric12030028

Assari, S. (2020c). Parental Education and Nucleus Accumbens Response to Reward Anticipation: Minorities' Diminished Returns. *Advances in social science and culture*, *2*(4), 132.

Assari, S. (2020d). Parental Education and Youth Inhibitory Control in the Adolescent Brain Cognitive Development (ABCD) Study: Blacks' Diminished Returns. *Brain Sciences*, *10*(5), 312. https://doi.org/10.3390/brainsci10050312

Assari, S. (2021a). Cingulo-opercular and Cingulo-parietal Brain Networks Functional Connectivity in Pre-adolescents: Multiplicative Effects of Race, Ethnicity, and Parental Education. *Research in Health Science*, *6*(2). https://doi.org/10.22158/rhs.v6n2p76

Assari, S. (2021b). Nucleus Accumbens Functional Connectivity with the Default Mode Network: Black Children's Diminished Returns of Household Income. *Research in Health Science*, *6*(3). https://doi.org/10.22158/rhs.v6n3p34

Assari, S., Akhlaghipour, G., Boyce, S., Bazargan, M., & Caldwell, C. H. (2020). African American Children's Diminished Returns of Subjective Family Socioeconomic Status on Fun Seeking. *Children*, *7*(7), 75. Retrieved from https://www.mdpi.com/2227-9067/7/7/75

Assari, S., & Bazargan, M. (2019). Unequal Associations between Educational Attainment and Occupational Stress across Racial and Ethnic Groups. *International journal of environmental research and public health*, *16*(19), 3539. Retrieved from https://www.mdpi.com/1660-4601/16/19/3539

Assari, S., Boyce, S., Akhlaghipour, G., Bazargan, M., & Caldwell, C. H. (2020). Reward Responsiveness in the Adolescent Brain Cognitive Development (ABCD) Study: African Americans' Diminished Returns of Parental Education. *Brain Sciences*, *10*(6), 391. Retrieved from https://www.mdpi.com/2076-3425/10/6/391

Assari, S., Boyce, S., & Bazargan, M. (2020). Subjective Family Socioeconomic Status and Adolescents' Attention: Blacks' Diminished Returns. *Children*, *7*(8), 80. Retrieved from https://www.mdpi.com/2227-9067/7/8/80

Assari, S., Boyce, S., Bazargan, M., & Caldwell, C. H. (2020a). African Americans' Diminished Returns of Parental Education on Adolescents' Depression and Suicide in the Adolescent Brain Cognitive Development (ABCD) Study. *European journal of investigation in health, psychology and education*, *10*(2), 656-668. Retrieved from https://www.mdpi.com/2254-9625/10/2/48

Assari, S., Boyce, S., Bazargan, M., & Caldwell, C. H. (2020b). Family income mediates the effect of parental education on adolescents' hippocampus activation during an n-back memory task. *Brain Sciences*, *10*(8), 520. https://doi.org/10.3390/brainsci10080520

Assari, S., Boyce, S., Caldwell, C. H., & Bazargan, M. (2020). Minorities' Diminished Returns of Parental Educational Attainment on Adolescents' Social, Emotional, and Behavioral Problems. *Children*, *7*(5), 49. https://doi.org/10.3390/children7050049

Assari, S., Caldwell, C. H., & Bazargan, M. (2019). Association between parental educational attainment and youth outcomes and role of race/ethnicity. *JAMA network open*, *2*(11), e1916018-e1916018. https://doi.org/10.1001/jamanetworkopen.2019.16018

Assari, S., Caldwell, C. H., & Mincy, R. B. (2018). Maternal Educational Attainment at Birth Promotes Future Self-Rated Health of White but Not Black Youth: A 15-Year Cohort of a National Sample. *J Clin Med*, *7*(5). http://doi.org/10.3390/jcm7050093

Assari, S., Caldwell, C. H., & Zimmerman, M. A. (2018). Family structure and subsequent anxiety symptoms; minorities' diminished return. *Brain Sciences*, *8*(6), 97.

Assari, S., & Curry, T. J. (2021). Parental Education Ain't Enough: A Study of Race (Racism), Parental Education, and Children's Thalamus Volume. *Journal of education and culture studies*, *5*(1), 1.

Assari, S., & Moghani Lankarani, M. (2018). *Poverty status and childhood asthma in white and black families: National Survey of Children's Health*. Paper presented at the Healthcare.

Auchter, A. M., Mejia, M. H., Heyser, C. J., Shilling, P. D., Jernigan, T. L., Brown, S. A., . . . Dowling, G. J. (2018). A description of the ABCD organizational structure and communication framework. *Developmental cognitive neuroscience*, *32*, 8-15. https://doi.org/10.1016/j.dcn.2018.04.003

Bailey, Z. D., Krieger, N., Agénor, M., Graves, J., Linos, N., & Bassett, M. T. (2017). Structural racism and health inequities in the USA: evidence and interventions. *The Lancet*, *389*(10077), 1453-1463.

Barr, P. B., Silberg, J., Dick, D. M., & Maes, H. H. (2018). Childhood socioeconomic status and longitudinal patterns of alcohol problems: Variation across etiological pathways in genetic risk. *Social Science & Medicine*, *209*, 51-58. https://doi.org/10.1016/j.socscimed.2018.05.027

75

Barrós-Loscertales, A., Costumero, V., Rosell-Negre, P., Fuentes-Claramonte, P., Llopis-Llacer, J. J., & Bustamante, J. C. (2020). Motivational factors modulate left frontoparietal network during cognitive control in cocaine addiction. *Addiction biology*, *25*(4), e12820.

Bøe, T., Øverland, S., Lundervold, A. J., & Hysing, M. (2012). Socioeconomic status and children's mental health: results from the Bergen Child Study. *Social psychiatry and psychiatric epidemiology*, *47*(10), 1557-1566. https://doi.org/10.1007/s00127-011-0462-9

Boissoneault, J., Lewis, B., & Nixon, S. J. (2019). Characterizing chronic pain and alcohol use trajectory among treatment-seeking alcoholics. *Alcohol*, *75*, 47-54.

Boissoneault, J., Stennett, B., & Robinson, M. E. (2020). Acute alcohol intake alters resting state functional connectivity of nucleus accumbens with pain-related corticolimbic structures. *Drug and alcohol dependence*, *207*, 107811. https://doi.org/10.1016/j.drugalcdep.2019.107811

Buck, S. A., Torregrossa, M. M., Logan, R. W., & Freyberg, Z. (2021). Roles of dopamine and glutamate co-release in the nucleus accumbens in mediating the actions of drugs of abuse. *The FEBS Journal*, *288*(5), 1462-1474. https://doi.org/10.1111/febs.15496

Butler, A. M., & Rodgers, C. R. (2019). Developing a policy brief on child mental health disparities to promote strategies for advancing equity among racial/ethnic minority youth. *Ethnicity & disease*, *29*(Suppl 2), 421. https://doi.org/10.18865/ed.29.S2.421

Cai, W., Griffiths, K., Korgaonkar, M. S., Williams, L. M., & Menon, V. (2019). Inhibition-related modulation of salience and frontoparietal networks predicts cognitive control ability and inattention symptoms in children with ADHD. *Molecular psychiatry*, 1-10.

Casey, B., Cannonier, T., Conley, M. I., Cohen, A. O., Barch, D. M., Heitzeg, M. M., . . . Garavan, H. (2018). The adolescent brain cognitive development (ABCD) study: imaging acquisition across 21 sites. *Developmental cognitive neuroscience*, *32*, 43-54.

Cerit, H., Davidson, P., Hye, T., Moondra, P., Haimovici, F., Sogg, S., . . . Whitfield-Gabrieli, S. (2019). Resting-State Brain Connectivity Predicts Weight Loss and Cognitive Control of Eating Behavior After Vertical Sleeve Gastrectomy. *Obesity*, *27*(11), 1846-1855.

Chen, Y., Ou, Y., Lv, D., Ma, J., Zhan, C., Yang, R., . . . Wang, Y. (2021). Decreased Nucleus Accumbens Connectivity at Rest in Medication-Free Patients with Obsessive-Compulsive Disorder. *Neural Plasticity*, *2021*. https://doi.org/10.1155/2021/9966378

Chetty, R., Hendren, N., Kline, P., & Saez, E. (2014). Where is the land of opportunity? The geography of intergenerational mobility in the United States. *The quarterly journal of Economics*, *129*(4), 1553-1623. https://doi.org/10.1093/qje/qju022

Cooper, J. C., & Knutson, B. (2008). Valence and salience contribute to nucleus accumbens activation. *Neuroimage*, *39*(1), 538-547. https://doi.org/10.1016/j.neuroimage.2007.08.009

Davis-Kean, P. E. (2005). The influence of parent education and family income on child achievement: the indirect role of parental expectations and the home environment. *Journal of Family Psychology*, *19*(2), 294. https://doi.org/10.1037/0893-3200.19.2.294

Ding, Y., Ji, G., Li, G., Zhang, W., Hu, Y., Liu, L., . . . Han, Y. (2020). Altered interactions among resting-state networks in individuals with obesity. *Obesity*, *28*(3), 601-608.

Domingo-Rodriguez, L., de Azua, I. R., Dominguez, E., Senabre, E., Serra, I., Kummer, S., . . . Andero, R. (2020). A specific prelimbic-nucleus accumbens pathway controls resilience versus vulnerability to food addiction. *Nature communications*, *11*(1), 1-16.

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: moving from correlation to causation. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 377-386.

Ferrario, C. R. (2020). Why did I eat that? Contributions of individual differences in incentive motivation and nucleus accumbens plasticity to obesity. *Physiology & Behavior*, 113114.

Fischl, B., & Dale, A. M. (2000). Measuring the thickness of the human cerebral cortex from magnetic resonance images. *Proceedings of the National Academy of Sciences*, *97*(20), 11050-11055.

Fischl, B., Sereno, M. I., & Dale, A. M. (1999). Cortical surface-based analysis: II: inflation, flattening, and a surface-based coordinate system. *NeuroImage*, *9*(2), 195-207.

Gao, Y., Shuai, D., Bu, X., Hu, X., Tang, S., Zhang, L., . . . Gong, Q. (2019). Impairments of large-scale functional networks in attention-deficit/hyperactivity disorder: a meta-analysis of resting-state functional connectivity. *Psychological medicine, 49*(15), 2475-2485.

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R., Heeringa, S., . . . Zahs, D. (2018). Recruiting the ABCD sample: Design considerations and procedures. *Developmental cognitive neuroscience*, *32*, 16-22. https://doi.org/10.1016/j.dcn.2018.04.004

Guryan, J., Hurst, E., & Kearney, M. (2008). Parental education and parental time with children. *Journal of Economic perspectives*, *22*(3), 23-46. https://doi.org/10.1257/jep.22.3.23

Hagler Jr, D. J., Hatton, S., Cornejo, M. D., Makowski, C., Fair, D. A., Dick, A. S., . . . Harms, M. P. (2019). Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *Neuroimage*, *202*, 116091.

Herrnstein, R. J., & Murray, C. (2010). *The bell curve: Intelligence and class structure in American life*: Simon and Schuster.

Heshmati, M., Christoffel, D. J., LeClair, K., Cathomas, F., Golden, S. A., Aleyasin, H., . . . Menard, C. (2020). Depression and social defeat stress are associated with inhibitory synaptic changes in the nucleus accumbens. *Journal of Neuroscience*, *40*(32), 6228-6233.

Hiscock, R., Dobbie, F., & Bauld, L. (2015). Smoking cessation and socioeconomic status: an update of existing evidence from a national evaluation of English stop smoking services. *BioMed Research International*, *2015*.

Hohenfeld, C., Werner, C. J., & Reetz, K. (2018). Resting-state connectivity in neurodegenerative disorders: Is there potential for an imaging biomarker? *NeuroImage: Clinical*, *18*, 849-870.

Hosokawa, R., & Katsura, T. (2018). Effect of socioeconomic status on behavioral problems from preschool to early elementary school–A Japanese longitudinal study. *PLoS One*, *13*(5), e0197961.

Jenkins, L. M., Chiang, J. J., Vause, K., Hoffer, L., Alpert, K., Parrish, T. B., . . . Miller, G. E. (2020). Subcortical structural variations associated with low socioeconomic status in adolescents. *Human brain mapping*, *41*(1), 162-171. https://doi.org/10.1002/hbm.24796

Jovicich, J., Czanner, S., Greve, D., Haley, E., van Der Kouwe, A., Gollub, R., . . . MacFall, J. (2006). Reliability in multi-site structural MRI studies: effects of gradient non-linearity correction on phantom and human data. *Neuroimage*, *30*(2), 436-443.

Kaczmarek, M., Stawińska-Witoszyńska, B., Krzyżaniak, A., Krzywińska-Wiewiorowska, M., & Siwińska, A. (2015). Who is at higher risk of hypertension? Socioeconomic status differences in blood pressure among Polish adolescents: a population-based ADOPOLNOR study. *European journal of pediatrics*, *174*(11), 1461-1473. https://doi.org/10.1007/s00431-015-2554-0

Kalil, A., Ryan, R., & Corey, M. (2012). Diverging destinies: Maternal education and the developmental gradient in time with children. *Demography*, *49*(4), 1361-1383.

Karcher, N. R., O'Brien, K. J., Kandala, S., & Barch, D. M. (2019). Resting-state functional connectivity and psychotic-like experiences in childhood: results from the adolescent brain cognitive development study. *Biological Psychiatry*, *86*(1), 7-15.

Kim, S. H., Park, B. Y., Byeon, K., Park, H., Kim, Y., Eun, Y. M., & Chung, J. H. (2019). The effects of high-frequency repetitive transcranial magnetic stimulation on resting-state functional connectivity in obese adults. *Diabetes, Obesity and Metabolism*, *21*(8), 1956-1966.

Lawson, G. M., Camins, J. S., Wisse, L., Wu, J., Duda, J. T., Cook, P. A., . . . Farah, M. J. (2017). Childhood socioeconomic status and childhood maltreatment: Distinct associations with brain structure. *PLoS One*, *12*(4), e0175690. https://doi.org/10.1371/journal.pone.0175690

Lawson, G. M., Duda, J. T., Avants, B. B., Wu, J., & Farah, M. J. (2013). Associations between children's socioeconomic status and prefrontal cortical thickness. *Developmental science*, *16*(5), 641-652. https://doi.org/10.1111/desc.12096

Lawson, G. M., Hook, C. J., Hackman, D. A., Farah, M. J., Griffin, J. A., Freund, L. S., & McCardle, P. (2014). Socioeconomic status and neurocognitive development: Executive function. *Executive function in preschool children: Integrating measurement, neurodevelopment, and translational research*, 1-28.

Lees, B., Squeglia, L. M., McTeague, L. M., Forbes, M. K., Krueger, R. F., Sunderland, M., . . . Mewton, L. (2021). Altered neurocognitive functional connectivity and activation patterns underlie psychopathology in preadolescence. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *6*(4), 387-398. https://doi.org/10.1016/j.bpsc.2020.09.007

Leijser, L. M., Siddiqi, A., & Miller, S. P. (2018). *Imaging evidence of the effect of socio-economic status on brain structure and development*. Paper presented at the Seminars in pediatric neurology.

Liu, R., Wang, Y., Chen, X., Zhang, Z., Xiao, L., & Zhou, Y. (2021). Anhedonia correlates with functional connectivity of the nucleus accumbens subregions in patients with major depressive disorder. *NeuroImage: Clinical*, *30*, 102599. https://doi.org/10.1016/j.nicl.2021.102599

78

Long, H., & Pang, W. (2016). Family socioeconomic status, parental expectations, and adolescents' academic achievements: A case of China. *Educational Research and Evaluation*, *22*(5-6), 283-304. https://doi.org/10.1080/13803611.2016.1237369

Ma, N., Liu, Y., Li, N., Wang, C.-X., Zhang, H., Jiang, X.-F., . . . Zhang, D.-R. (2010). Addiction related alteration in resting-state brain connectivity. *Neuroimage*, *49*(1), 738-744.

Mackey, A. P., Finn, A. S., Leonard, J. A., Jacoby-Senghor, D. S., West, M. R., Gabrieli, C. F., & Gabrieli, J. D. (2015). Neuroanatomical correlates of the income-achievement gap. *Psychological science*, *26*(6), 925-933. https://doi.org/10.1177/0956797615572233

Markett, S., Reuter, M., Montag, C., Voigt, G., Lachmann, B., Rudorf, S., . . . Weber, B. (2014). Assessing the function of the fronto-parietal attention network: insights from resting-state fMRI and the attentional network test. *Human brain mapping*, *35*(4), 1700-1709.

Martinez, S. A., Beebe, L. A., Thompson, D. M., Wagener, T. L., Terrell, D. R., & Campbell, J. E. (2018). A structural equation modeling approach to understanding pathways that connect socioeconomic status and smoking. *PLoS One*, *13*(2), e0192451.

McDermott, C. L., Seidlitz, J., Nadig, A., Liu, S., Clasen, L. S., Blumenthal, J. D., . . . Patel, R. (2019). Longitudinally mapping childhood socioeconomic status associations with cortical and subcortical morphology. *Journal of Neuroscience*, *39*(8), 1365-1373.

McTeague, L. M., Huemer, J., Carreon, D. M., Jiang, Y., Eickhoff, S. B., & Etkin, A. (2017). Identification of common neural circuit disruptions in cognitive control across psychiatric disorders. *American Journal of Psychiatry*, *174*(7), 676-685.

Merz, E. C., Tottenham, N., & Noble, K. G. (2018). Socioeconomic status, amygdala volume, and internalizing symptoms in children and adolescents. *Journal of Clinical Child & Adolescent Psychology*, *47*(2), 312-323. https://doi.org/10.1080/15374416.2017.1326122

Morris, A. S., Silk, J. S., Steinberg, L., Myers, S. S., & Robinson, L. R. (2007). The role of the family context in the development of emotion regulation. *Social development*, *16*(2), 361-388.

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kan, E., Kuperman, J. M., . . . Libiger, O. (2015). Family income, parental education and brain structure in children and adolescents. *Nature neuroscience*, *18*(5), 773. https://doi.org/10.1038/nn.3983

Olney, J. J., Warlow, S. M., Naffziger, E. E., & Berridge, K. C. (2018). Current perspectives on incentive salience and applications to clinical disorders. *Current opinion in behavioral sciences*, *22*, 59-69. https://doi.org/10.1016/j.cobeha.2018.01.007

Pabayo, R., Molnar, B. E., & Kawachi, I. (2014). The role of neighborhood income inequality in adolescent aggression and violence. *Journal of Adolescent Health*, *55*(4), 571-579.

Piotrowska, P. J., Stride, C. B., Croft, S. E., & Rowe, R. (2015). Socioeconomic status and antisocial behaviour among children and adolescents: A systematic review and meta-analysis. *Clinical psychology review*, *35*, 47-55. https://doi.org/10.1016/j.cpr.2014.11.003

Rakesh, D., Zalesky, A., & Whittle, S. (2021). Similar but distinct–Effects of different socioeconomic indicators on resting state functional connectivity: Findings from the Adolescent Brain Cognitive Development (ABCD) Study®. *Developmental cognitive neuroscience*, *51*, 101005.

Rapuano, K. M., Laurent, J. S., Hagler, D. J., Hatton, S. N., Thompson, W. K., Jernigan, T. L., . . . Watts, R. (2020). Nucleus accumbens cytoarchitecture predicts weight gain in children. *Proceedings of the National Academy of Sciences*, *117*(43), 26977-26984.

Reiss, F. (2013). Socioeconomic inequalities and mental health problems in children and adolescents: a systematic review. *Social Science & Medicine*, *90*, 24-31.

Rekker, R., Pardini, D., Keijsers, L., Branje, S., Loeber, R., & Meeus, W. (2015). Moving in and out of poverty: The within-individual association between socioeconomic status and juvenile delinquency. *PLoS One*, *10*(11), e0136461. https://doi.org/10.1371/journal.pone.0136461

Research, A., & Staff, C. R. E. (2018). NIH's Adolescent Brain Cognitive Development (ABCD) Study. *Alcohol research: current reviews*, *39*(1), 97.

Richels, C. G., Johnson, K. N., Walden, T. A., & Conture, E. G. (2013). Socioeconomic status, parental education, vocabulary and language skills of children who stutter. *Journal of communication disorders*, *46*(4), 361-374. https://doi.org/10.1016/j.jcomdis.2013.07.002

Salgado, S., & Kaplitt, M. G. (2015). The nucleus accumbens: a comprehensive review. *Stereotactic and functional neurosurgery*, *93*(2), 75-93. https://doi.org/10.1159/000368279

Shaikh, R. A., Siahpush, M., Singh, G. K., & Tibbits, M. (2015). Socioeconomic status, smoking, alcohol use, physical activity, and dietary behavior as determinants of obesity and body mass index in the United States: findings from the National Health Interview Survey. *International Journal of MCH and AIDS*, *4*(1), 22. https://doi.org/10.21106/ijma.53

Smith, J. L., Allen, J. W., Haack, C., Wehrmeyer, K., Alden, K., Lund, M. B., & Mascaro, J. S. (2021). The impact of app-delivered mindfulness meditation on functional connectivity and self-reported mindfulness among health profession trainees. *Mindfulness*, *12*(1), 92-106.

Smith, S. M., Fox, P. T., Miller, K. L., Glahn, D. C., Fox, P. M., Mackay, C. E., . . . Laird, A. R. (2009). Correspondence of the brain's functional architecture during activation and rest. *Proceedings of the National Academy of Sciences*, *106*(31), 13040-13045.

Sousa, S. S., Sampaio, A., López-Caneda, E., Bec, C., Gonçalves, Ó. F., & Crego, A. (2020). Increased nucleus accumbens volume in college binge drinkers-preliminary evidence from manually segmented MRI analysis. *Frontiers in psychiatry*, *10*, 1005.

Spera, C., Wentzel, K. R., & Matto, H. C. (2009). Parental aspirations for their children's educational attainment: Relations to ethnicity, parental education, children's academic performance, and parental perceptions of school climate. *Journal of Youth and Adolescence*, *38*(8), 1140-1152.

Stelly, C. E., Girven, K. S., Lefner, M. J., Fonzi, K. M., & Wanat, M. J. (2021). Dopamine release and its control over early Pavlovian learning differs between the NAc core and medial NAc shell. *Neuropsychopharmacology*, 1-8. https://doi.org/10.1101/2020.07.29.227876

Su, M., Li, P., Zhou, W., & Shu, H. (2021). Effects of socioeconomic status in predicting reading outcomes for children: The mediation of spoken language network. *Brain and Cognition*, *147*, 105655. https://doi.org/10.1016/j.bandc.2020.105655

Tan, Y., Tan, J., Deng, J., Cui, W., He, H., Yang, F., . . . Zhang, X. (2015). Alteration of basal ganglia and right frontoparietal network in early drug-naive Parkinson's disease during heat pain stimuli and resting state. *Frontiers in human neuroscience*, *9*, 467. https://doi.org/10.3389/fnhum.2015.00467

Valencia, M. L. C., Tran, B. T., Lim, M. K., Choi, K. S., & Oh, J.-K. (2019). Association between socioeconomic status and early initiation of smoking, alcohol drinking, and sexual behavior among Korean adolescents. *Asia Pacific Journal of Public Health*, *31*(5), 443-453. https://doi.org/10.1177/1010539519860732

Van Houdt, C. A., van Wassenaer-Leemhuis, A. G., Oosterlaan, J., van Kaam, A. H., & Aarnoudse-Moens, C. S. (2019). Developmental outcomes of very preterm children with high parental education level. *Early human development*, *133*, 11-17. https://doi.org/10.1016/j.earlhumdev.2019.04.010

Weissman, D. G., Schriber, R. A., Fassbender, C., Atherton, O., Krafft, C., Robins, R. W., . . . Guyer, A. E. (2015). Earlier adolescent substance use onset predicts stronger connectivity between reward and cognitive control brain networks. *Developmental cognitive neuroscience*, *16*, 121-129. https://doi.org/10.1016/j.dcn.2015.07.002

Wells III, W. M., Viola, P., Atsumi, H., Nakajima, S., & Kikinis, R. (1996). Multi-modal volume registration by maximization of mutual information. *Medical image analysis*, *1*(1), 35-51. https://doi.org/10.1016/S1361-8415(01)80004-9

Zhang, X.-Y., Peng, S.-Y., Shen, L.-P., Zhuang, Q.-X., Li, B., Xie, S.-T., . . . Zhang, Q. (2020). Targeting presynaptic H3 heteroreceptor in nucleus accumbens to improve anxiety and obsessive-compulsive-like behaviors. *Proceedings of the National Academy of Sciences*, *117*(50), 32155-32164. https://doi.org/10.1073/pnas.2008456117
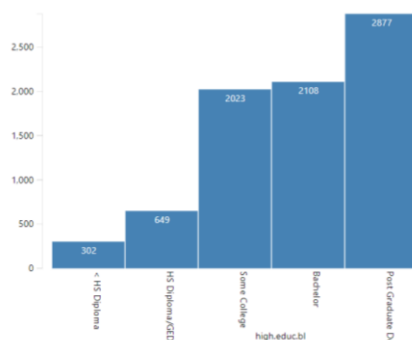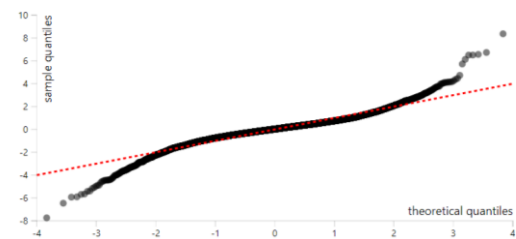

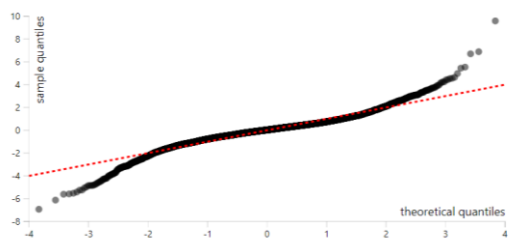(a) Distribution of parental education

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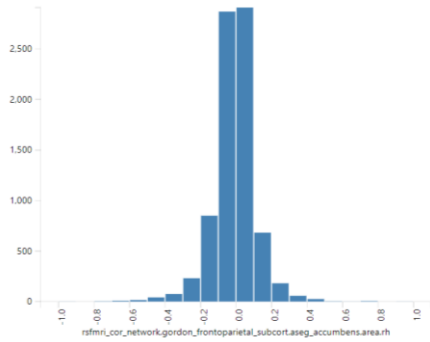
(b) Distribution for the functional connectivity between the right NAcc and frontoparietal network
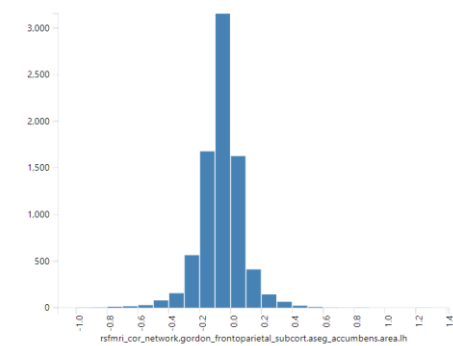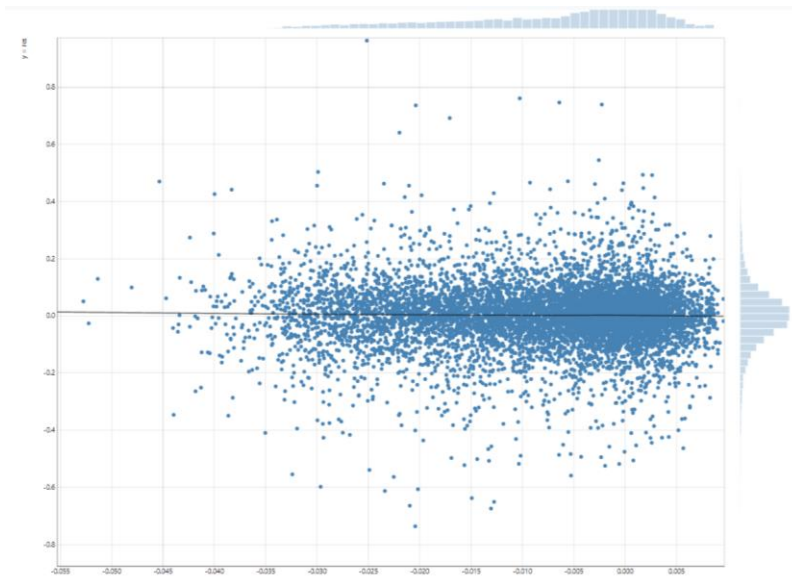

(c) Distribution for the functional connectivity between the left NAcc and frontoparietal network
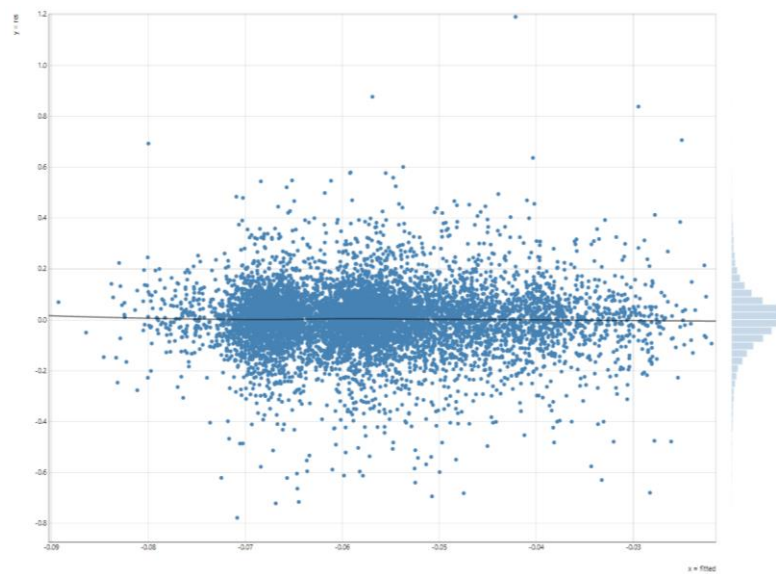

(d) Quantiles distribution for the association between parental education and functional connectivity between the right NAcc and frontoparietal network

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

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(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