Research in Health Science
ISSN 2470-6205 (Print) ISSN 2470-6213 (Online)
Vol. 6, No. 2, 2021
www.scholink.org/ojs/index.php/rhs

Original Paper

Cingulo-opercular and Cingulo-parietal Brain Networks Functional Connectivity in Pre-adolescents: Multiplicative Effects of Race, Ethnicity, and Parental Education

Shervin Assari[1,2,3]

[1] Department of Family Medicine, College of Medicine, Charles R. Drew University of Medicine and Science, Los Angeles, CA 90059, USA

[2] Department of Urban Public Health, Charles R. Drew University of Medicine and Science, Los Angeles, CA 90059, USA

[3] Marginalization-related Diminished Returns (MDRs) Research Center, Charles R. Drew University of Medicine and Science, Los Angeles, CA 90059, USA

Abstract

Introduction: *A growing body of research has shown a diminished association between socioeconomic status (SES) indicators and a wide range of neuroimaging indicators for racial and ethnic minorities compared to majority groups. However, less is known about these effects for resting-state functional connectivity between various brain networks.* ***Purpose:*** *This study investigated racial and ethnic variation in the correlation between parental education and resting-state functional connectivity between the cingulo-opercular (CO) and cingulo-parietal (CP) networks in children.* ***Methods:*** *This cross-sectional study used data from the Adolescent Brain Cognitive Development (ABCD) study; we analyzed the resting-state functional Magnetic Resonance Imaging (rsfMRI) data of 8,464 American pre-adolescents between the ages of 9 and 10. The main outcome measured was resting-state functional connectivity between the CO and CP networks calculated using rsfMRI. The independent variable was parental education, which was treated as a nominal variable. Age, sex, and family marital status were the study covariates. Race and ethnicity were the moderators. Mixed-effects regression models were used for data analysis, with and without interaction terms between parental education and race and ethnicity.* ***Results:*** *Higher parental education was associated with lower resting-state functional connectivity between the CO and CP networks. Race and ethnicity both showed statistically significant interactions with parental education on children's resting-state functional connectivity between CO and CP networks, suggesting that the correlation between parental education and the resting-state functional connectivity was significantly weaker for Black and Hispanic pre-adolescents compared to White and non-Hispanic pre-adolescents.* ***Conclusions:*** *In line with the Minorities' Diminished Returns* *theory, the association between parental education and pre-adolescents resting-state functional connectivity between CO and CP networks may be weaker in Black and Hispanic children than in White and non-Hispanic children. The weaker link between parental education and brain functional connectivity for Blacks and Hispanics than for Whites and non-Hispanics may reflect the racism, racialization, and social stratification that minimizes the returns of SES indicators, such as parental education for non-Whites, who become others in the US.*

Keywords

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

1. Introduction

Advancement of neuroimaging modalities, such as resting-state functional magnetic resonance imaging (rsfMRI), has led to the advancement of our understanding regarding children's brain development [1-3], and how early life experiences such as childhood socioeconomic status (SES) influence brain development [4-7]. Several rsfMRI indicators correlate with the higher-level cognitive function of children, including but not limited to, memory, learning and executive function [8]. Altered MRI measures may reflect a wide range of cognitive disorders from attention deficit hyperactive disorder (ADHD) [9,10], autism spectrum disorder (ASD) [10-12], Alzheimer's [13], and other conditions in which working memory [14,15], executive function [14,16], language development [14,17] and emotion regulation [18] are altered.

Socioeconomic status (SES) indicators, such as parental education, are linked to function and structure of the brain [15,19-22] which correlate with various aspects of emotion and cognitive development in domains such as language [23], self-regulation (the ability to monitor and control one's behavior and emotions) [20,24], memory[25], socio-emotional processing [25], and behaviors [26]. High SES is a proxy of high-quality parenting and lower exposure to stress, adversity, trauma, and poverty, with all of the aforementioned being risk factors of poor brain development [27]. High parental education is commonly linked to high parenting quality [28] and cognitively stimulating environments [29,30]. Children from highly educated families are more likely to be raised in low-*stress environments*, with parental support and engagement, promoting brain development [31,32]. High parental education is also linked to the availability of material and financial resources to the child [29]. As a result, high parental education is shown to reduce the risk of substance use [33,34], such as alcohol addictions [35,36] and smoking [37,38]. Similarly, high parental education is linked to a lower risk of antisocial behavior [39], aggressive behavior [40], behavioral problems [41], mental disorders [42,43], and cognitive problems [44] in children and adolescents.

Recent research, however, has suggested that parental education may have far fewer effects for minority status, while income causes more equal outcomes across racial and ethnic groups [45]. In fact, people of color with high education are much more likely to be discriminated against in the workplace [46]. As a result, Black and Hispanic families may earn less income and generate less wealth compared to non-Hispanic White families [47]. However, most research has indicated that parental education is likely to generate fewer outcomes for Black and Hispanic people than non-Hispanic White individuals [45,48,49]. Income tends to lead to equal outcomes across different racial and ethnic groups [29]. A cross-sectional study of children between 3 and 20 years of age showed an association between many brain regions that have implications for reading, language, executive functions, social cognition, and spatial skills with the number of years of parental education [50].

Early life experiences, such as childhood SES, may impact neural changes that can be measured using MRI [51]. Many studies to date have established a link between SES indicators and structural and functional aspects of the brain [52,53]. For example, parental SES is linked to cortical thickness, surface area, and volume [54]. Studying MRI changes in function and structure of brain regions may help us better understand problems such as anxiety [55], obstructive sleep apnea [56], obesity [57], chronic stress [58], ADHD [59], major depressive disorder [60]and learning disorders [61]. Unfortunately, little is known about how childhood SES indicators, such as parental education, influence functional connectivity of the brain at rest. Similarly, there is a need to examine whether racial groups differ in the associations between parental education and pre-adolescents resting-state functional connectivity between cingulo-opercular (CO) and cingulo-parietal (CP) networks.

Most of the existing studies on SES impacts on brain development have focused on average effects overall, without comparing groups for such effects. Similarly, most of the literature has reported on predominantly middle-class White people. In addition, most of the studies have considered structural or functional measures of single regions of interest. This has been the case for most neuroimaging studies during the past two decades [52,53,62,63]. There is no report on whether racial groups are different or similar in the association between parental education and pre-adolescents resting-state functional connectivity between CO and CP networks. Even when the studies have included race as a variable, they have mainly focused on the additive influences of race and SES, rather than multiplicative effects that allow SES effects to vary by race. While SES and race overlap (i.e., they are both proxies of stress, trauma, and adversities) [64-66], SES effects seem to be lesser for Black and Hispanic families than non-Hispanic White families [67-69]. Thus, it is essential to test how race and ethnicity alter what we know about the effects of SES on brain functions [64,66], particularly connectivity between various networks and structures, which is rarely studied [70,71].

A growing literature on Marginalization-related Diminished Returns (MDRs) framework [49,72] has documented weaker beneficial influences of SES indicators, especially parental education, on developmental, behavioral, and health outcomes in racial and ethnic minority families because of discrimination, racism, racialization, stratification, othering, and marginalization [29]. Weaker effects of SES on depression [73], attention [74], impulse control [75], social and behavioral problems [76,77], inhibitory control [78], suicidality [28], anxiety [79], and attention deficit hyperactive disorder (ADHD) [80] are shown for Black and Hispanic children than non-Hispanic White children. As a consequence of these MDRs, we observe sustained disparities in behavior and development in Black and Hispanic families with high SES, while the risk drastically drops for high SES non-Hispanic White individuals [50]. As mentioned before, to our knowledge, we are not aware of any previous studies examining the relationship between parental education and pre-adolescents resting-state functional connectivity between brain networks by race.

Among various functional connectivity measures evaluated by rsfMRI that are linked to SES are connectivity between CO and CP brain networks [81]. Analysis of connectivity between various brain networks is important because they reflect cross-system-level measures that reflect harmonious brain function across networks. The functional connectivity between CO and CP and other brain networks are linked to higher-order cognitive function of the brain, and their altered connectivity across these networks may be documented in the presence of altered cognition, emotions, and psychiatric disorders [82].

Among various brain networks is the CO network. The CO network is composed of the thalamus, dorsal anterior cingulate cortex, and anterior insula/operculum, and is involved in self-monitoring in the cognitive control and sensorimotor processing [83]. The CO function is central to monitoring one's performance, which helps detect errors so the individual can prevent future cognitive and motion errors and mistakes. The CO network, however, has pervasive activity, co-activation, and connectivity with several other control-related networks that has made it difficult for scientists to characterize CO brain network's specific function. However, its elevated performance is linked to elevated monitoring, and its altered connectivity and function are characteristics of multiple psychiatric disorders, including psychotic conditions. Heightened brain connectivity between the CO network and other networks may result in higher levels of performance monitoring [83].

Another brain network is the cognitive/attention network [84]. Disorder and different activation and connectivity of this network is shown in attention disorders [85]. In the Adolescent Brain Cognitive Development research (ABCD) study, an increase in connectivity between CP network and other networks has been linked to less psychotic symptoms, even after accounting for family history of psychotic disorders, internalizing symptoms, and cognitive performance [82].

1.1 Aims

This study assessed data from the Adolescent Brain Cognitive Development research (ABCD) [82,86-89] to explore racial variations for the association between parental education and resting-state functional connectivity between CO and CP networks in a national sample of 9-to-10-year-old pre-adolescents. In this study, we went beyond testing additive effects of race, ethnicity, and parental education on the resting-state functional connectivity between CO and CP networks. Instead, we explored multiplicative effects of race and ethnicity with parental education on resting-state functional connectivity between the CO and CP networks. This allows the effects of parental education to vary by race and ethnicity, which is in line with the MDRs. Built on the MDRs theory [48,77], we hypothesized that parental education would have a weaker effect on resting-state functional connectivity between CO and CP networks for Hispanic and Black pre-adolescents compared to non-Hispanic White pre-adolescents. This means that we considered Black and Hispanic pre-adolescents' resting-state functional connectivity between the CO and CP networks to remain at risk regardless of their parental education, whereas we expect the lowest risk in resting-state functional connectivity between CO and CP networks among non-Hispanic White pre-adolescents with high parental education.

2. Methods

Design and Settings

This secondarily cross-sectional analysis was based on the Adolescent Brain Cognitive Development (ABCD) study [82,86,87,89,90], which is a guiding light of examining children's brain development with a considerable SES, sex, racial, and ethnic diversity in the United States [86,91]. We briefly reviewed critical aspects of the study, even though there is some comprehensive information regarding ABCD samples, methods, measures, and imaging techniques [91].

Participants and Sampling

The ABCD study participants were 9 to 10 years old and were selected from 21 sites across 15 states, encompassing over 20% of the total United States population of 9-10-year-old children [91,92]. For sampling and selection, school selection was guided by sex, race, ethnicity, SES, and urbanicity. These recruitment processes were precisely designed, implemented, and evaluated across the 21 study sites [93]. In fact, although the ABCD sample was not representative or random, due to careful sampling, it is a near estimation of U.S. children over sociodemographic and demographic factors. The results therefore are reliable in regard to age, SES, ethnicity, sex, and urbanicity. Garavan et al. carefully described the sampling procedure of the ABCD study [92]. 8,464 children, aged 9 to 10-year-olds, participated in the study, regardless of race, ethnicity, and psychopathologies, which means that participants were not excluded based on the presence or absence of any psychopathology [92]. However, we only included participants with complete data and those who met criteria for rsfMRI. The formula for selection of our participants was: (fsqc_qc="pass") and (rsfmri_cor_network.gordon_ntpoints>375)

Brain Imaging

Resting-state (task-negative) functional MRI (resfMRI) was used to estimate pre-adolescents' resting-state functional connectivity between the CO and CP networks. Brain imaging in the ABCD study was based on three 3 tesla (T) scanner platforms: Philips Healthcare, GE Healthcare, and Siemens Healthcare [94]. T1-weighted and T2-weighted brain images, carefully harmonized, were drawn from The MRI devices [87]. In order to reduce bias due to variation in imaging sites, images were corrected for gradient non-linearity distortions [95]. These available pre-processed structural data were calculated based on T1- and T2-weighted images that maximize mutual information's relative position and orientation across images [96]. By using tissue segmentation and sparse spatial smoothing, the ABCD performed intensity non-uniformity correction. Moreover, images were resampled with 1-mm isotropic voxels into rigid alignment within the brain atlas. Furthermore, using FreeSurfer software, version 5.3.0 (Harvard University), volumetric measures were constructed. Images had also undergone surface optimization [97,98] and nonlinear registration to a spherical surface-based atlas [98].

Study Variables

The study variables included parental education (independent variable), race and ethnicity (moderator), age, sex, family structure (confounders), and resting-state functional connectivity between CO and CP networks (dependent variable).

Independent Variable

Parental Education: Parental education was a five-level nominal variable: less than high school diploma, high school diploma/GED, some college, bachelors' degree, and graduate studies. Less than a high school diploma was the reference group.

Dependent variable

Resting-state functional connectivity between CO and CP networks: The outcome was resting-state functional connectivity between CO and CP networks, measured by resting-state (task-negative) functional MRI. This variable was a continuous measure and reflected Pearson correlation test between the BOLD measures of the two networks over time. CO and CP were defined according to the Gordon parcellation scheme that divides brain networks into 12 predefined resting state networks (RSN) [99]. In this study, we only used data of CO and CP. To calculate this information, the ABCD completed 4–5 five-minute resting state scans (eyes open). This was used to ensure at least eight minutes of relatively low-motion data. Preprocessing was carried out by the ABCD Data Analysis and Informatics Core using the standardized ABCD pipeline [100]. Next, fMRI time courses were projected onto FreeSurfer's cortical surface. Using these time courses, both within- and between-network connectivity (Pearson correlation) were calculated on the basis of standard protocols based on the Gordon scheme[99]. For more information regarding these processes, please see here [100,101]. Family SES is shown to be correlated with the functional connectivity between CO and CO [82]. **Appendix Figures** show that our outcome is inversely correlated with memory/executive function and reward responsiveness.

***Moderators**:*

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

Ethnicity. It was a dichotomous variable coded as Hispanic = 1 and non-Hispanic = 0 **Confounders:**

Age. Age was a continuous variable. Parents reported the child's age as months.

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

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

Data Analysis

Data Exploration and Analysis Portal (DEAP), which is a user-friendly online platform for multivariable analysis of the ABCD data, was used for data analysis. We reported mean (standard deviation (S.D.)) and frequency (%) for descriptive purposes. We also performed ANOVA and Chi-square for bivariate tests, including comparing racial groups for study variables. We used mixed-effects regression models; given participants are nested to families and families are nested to sites. The primary outcome was the children's resting-state functional connectivity between the CO and CP networks. The independent variable was parental education; race and ethnicity were the moderators.

Moreover, age, sex, and family marital status were the covariates. To run multivariable analyses, three mixed-effects regression models were run (**Appendix Table**). *Model 1* tested the additive effects of parental education, race, and ethnicity, with the same covariates, without interaction terms. *Model 2* tested the interaction term between parental education and race on resting-state functional connectivity between the CO and CP networks. *Model 3* tested the interaction term between parental education and ethnicity on resting-state functional connectivity between the CO and CP networks. Before running models, we checked the normal distribution of our outcome, lack of collinearity between predictors, and the distribution of errors for our model. Regression coefficient (b), SE, and p-value were reported.

Ethical Aspect

While the original ABCD research protocol went through an Institutional Review Board (IRB) in several institutions, including the University of California, San Diego (UCSD), our analysis was found to be exempt from further IRB review by the Charles R Drew University of Medicine and Science (CDU). Moreover, several institutional IRBs approved the study protocol. All children provided assent. Parents provided consent [91].

3. Results

This study was performed on 8,464 children aged between 9 to 10 years old. From this number, 3,699 (51.4%) were male and 3,669 (48.0%) were female. The participants were White (5,665; 66.9%), 1,197 (14.1%) were Black, 187 (2.2%) were Asian American, and 1,415 (16.7%) were other/mixed race. From all, 1,673 (19.8%) were Hispanic and 6,791 (80.2%) were non-Hispanic. Racial groups did not differ in age; however, ethnic groups did differ in age. Racial groups did differ in sex; however, ethnic groups did not differ in sex. Black and mixed/other race participants showed lowest parental education respectively compared to White children. Hispanic adolescents showed lower parental education than non-Hispanic adolescents. Racial and ethnic groups also varied in family structure. Also, resting-state functional connectivity between CO and CP networks was significantly different across racial and ethnic groups (**Table 1**).

Table 2 summarizes mixed-effects regression models' fit statistics, performed in the total sample. *Model 2* and *Model 3* showed a better fit when compared to *Model 1*, suggesting that interaction between parental education and race or ethnicity helped explain the variance of the outcome.

As shown by **Table 3** and **Figure 1**, when all confounders were controlled, parental education showed a positive association with the resting-state functional connectivity between CO and CP networks. *Model 2* showed that parental education had interactions with race on the outcome. This interaction was negative, suggesting that the positive effect of parental education was lesser for Black than White children. *Model 3* showed that parental education interacted with ethnicity on the outcome. This interaction was also negative, suggesting that the positive effect of parental education was lesser for Hispanic than non-Hispanic children.

Table 1. Descriptive Characteristics Overall and by Race (n = 8464)

	level	Overall	White	Black	Asian	Other/Mixed	p	Non-Hispanic	Hispanic	p
n		8464	5665	1197	187	1415		6791	1673	
		Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)		Mean(SD)	Mean(SD)	
Age (month)		119.44 (7.53)	119.50 (7.54)	119.35 (7.29)	119.99 (8.00)	119.23 (7.61)	0.463	119.56 (7.50)	118.96 (7.64)	0.003
RsfMRI Functional Connectivity CO and CP Networks		-0.01 (0.10)	-0.01 (0.09)	-0.02 (0.11)	-0.02 (0.10)	-0.01 (0.09)	0.003	-0.01 (0.09)	-0.02 (0.10)	0.002
		n(%)	n(%)	n(%)	n(%)	n(%)		n(%)	n(%)	
Parental Education	< HS Diploma	335 (4.0)	142 (2.5)	96 (8.0)	5 (2.7)	92 (6.5)	< 0.001	125 (1.8)	210 (12.6)	< 0.001
	HS Diploma/GED	701 (8.3)	272 (4.8)	268 (22.4)	2 (1.1)	159 (11.2)		440 (6.5)	261 (15.6)	
	Some College	2149 (25.4)	1171 (20.7)	484 (40.4)	14 (7.5)	480 (33.9)		1576 (23.2)	573 (34.2)	
	Bachelor	2237 (26.4)	1693 (29.9)	172 (14.4)	47 (25.1)	325 (23.0)		1914 (28.2)	323 (19.3)	
	Post Graduate Degree	3042 (35.9)	2387 (42.1)	177 (14.8)	119 (63.6)	359 (25.4)		2736 (40.3)	306 (18.3)	
Race	White	5665 (66.9)	5665 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	< 0.001	4654 (68.5)	1011 (60.4)	< 0.001
	Black	1197 (14.1)	0 (0.0)	1197 (100.0)	0 (0.0)	0 (0.0)		1137 (16.7)	60 (3.6)	
	Asian	187 (2.2)	0 (0.0)	0 (0.0)	187 (100.0)	0 (0.0)		170 (2.5)	17 (1.0)	
	Other/Mixed	1415 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	1415 (100.0)		830 (12.2)	585 (35.0)	
Hispanic	No	6791 (80.2)	4654 (82.2)	1137 (95.0)	170 (90.9)	830 (58.7)	< 0.001	6791 (100.0)	0 (0.0)	< 0.001
	Yes	1673 (19.8)	1011 (17.8)	60 (5.0)	17 (9.1)	585 (41.3)		0 (0.0)	1673 (100.0)	
Sex (%)	Female	4263 (50.4)	2792 (49.3)	636 (53.1)	111 (59.4)	724 (51.2)	0.005	3418 (50.3)	845 (50.5)	0.919
	Male	4201 (49.6)	2873 (50.7)	561 (46.9)	76 (40.6)	691 (48.8)		3373 (49.7)	828 (49.5)	
Married Family	No	2519 (29.8)	1126 (19.9)	832 (69.5)	29 (15.5)	532 (37.6)	< 0.001	1858 (27.4)	661 (39.5)	< 0.001
	Yes	5945 (70.2)	4539 (80.1)	365 (30.5)	158 (84.5)	883 (62.4)		4933 (72.6)	1012 (60.5)	

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

Table 2. Effect Sizes and % Variance Explained

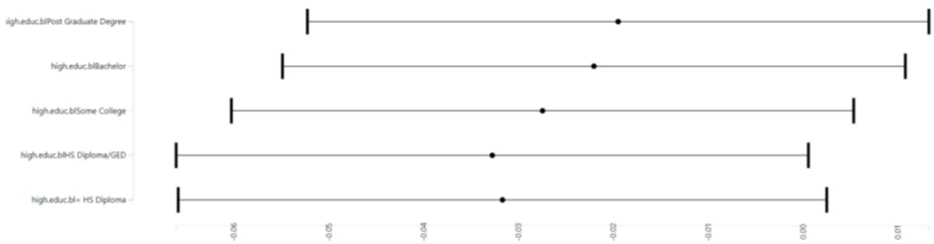
	Model 1	*Model 2* M1 + Race x Parental Education	*Model 3* M1 + Ethnicity x Parental Education
N	8464	8464	8464
R-squared	0.00741	0.01005	0.00876
ΔR-squared	0.00154	0.00526	0.00387
ΔR-squared %	0.15%	0.53%	0.39%

Table 3. Regressions in the Overall Sample and by Race with CO and CP Networks Functional Connectivity as the Outcome

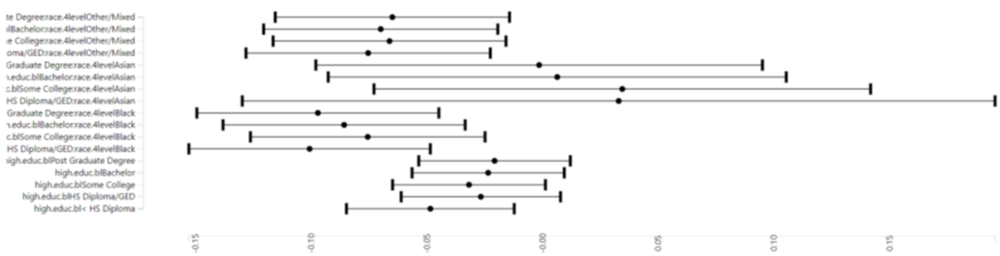
	Model 1				*Model 2*				*Model 3*			
	Estimate	Std. Error	Pr(> | t|)	sig	Estimate	Std. Error	Pr(> | t|)	sig	Estimate	Std. Error	Pr(> | t|)	sig
Parental Education (HS Diploma/GED)	-0.00108	0.00642	0.8669451		0.02182	0.00997	0.0287088	*	-0.02283	0.00976	0.0193869	*
Parental Education (Some College)	0.00422	0.00576	0.4635545		0.01671	0.00868	0.054267	#	-0.01816	0.00908	0.0455952	*
Parental Education (Bachelor)	0.00964	0.00595	0.105509		0.02498	0.00868	0.0039954	**	-0.01257	0.00924	0.1735315	
Parental Education (Post Graduate Degree)	0.01219	0.00594	0.0400468	*	0.02775	0.00862	0.0012923	**	-0.00891	0.00920	0.3326101	
Race (Black)	-0.00429	0.00346	0.2153322		0.03140	0.01298	0.0155597	*	-0.00549	0.00354	0.1214157	
Race (Asian)	-0.01648	0.00713	0.0208414	*	-0.06731	0.04321	0.1192914		-0.01622	0.00713	0.0229061	*
Race (Other/Mixed)	-0.00147	0.00297	0.619932		0.01693	0.01280	0.1859848		-0.00162	0.00297	0.586294	
Hispanic	-0.00490	0.00290	0.0910679	#	-0.00364	0.00295	0.2181547		-0.03841	0.01112	0.0005538	***
Sex (Male)	0.00994	0.00209	1.9e-06	***	0.00992	0.00209	2e-06	***	0.00996	0.00209	1.8e-06	***
Married Family	0.00146	0.00263	0.5792842		0.00186	0.00264	0.4815058		0.00175	0.00264	0.5065686	
Age (Month)	0.00009	0.00014	0.5045614		0.00010	0.00014	0.4873677		0.00009	0.00014	0.4995918	
Black x Parental Education (HS Diploma/GED)	-	-	-	-	-0.05220	0.01519	0.0005919	***	-	-	-	
Black x Parental Education (Some College)	-	-	-	-	-0.02706	0.01382	0.0502717	#	-	-	-	
Black x Parental Education (Bachelor)	-	-	-	-	-0.03729	0.01502	0.0130876	*	-	-	-	
Black x Parental Education (Post Graduate Degree)	-	-	-	-	-0.04863	0.01493	0.0011287	**	-	-	-	
Asian x Parental Education (HS Diploma/GED)	-	-	-	-	0.08140	0.08018	0.3100006		-	-	-	
Asian x Parental Education (Some College)	-	-	-	-	0.08296	0.05022	0.0985438	.	-	-	-	
Asian x Parental Education (Bachelor)	-	-	-	-	0.05485	0.04545	0.2276022		-	-	-	
Asian x Parental Education (Post Graduate Degree)	-	-	-	-	0.04703	0.04413	0.2866676		-	-	-	

Other/Mix x Parental Education (HS Diploma/GED)	-	-	-	-	-0.02689	0.01600	0.0928644	.	-	-	-	
Other/Mix Parental Education (Some College)	-	-	-	-	-0.01765	0.01383	0.2017625		-	-	-	
Other/Mix Parental Education (Bachelor)	-	-	-	-	-0.02145	0.01408	0.127556		-	-	-	
Other/Mix Parental Education (Post Graduate Degree)	-	-	-	-	-0.01642	0.01391	0.2380349		-	-	-	
Hispanic x Parental Education (HS Diploma/GED)	-	-	-	-	-	-	-		0.03561	0.01321	0.0070317	**
Hispanic x Parental Education (Some College)	-	-	-	-	-	-	-		0.03784	0.01192	0.0015061	**
Hispanic x Parental Education (Bachelor)	-	-	-	-	-	-	-		0.03842	0.01251	0.0021487	**
Hispanic x Parental Education (Post Graduate Degree)	-	-	-	-	-	-	-		0.02919	0.01251	0.0196688	*

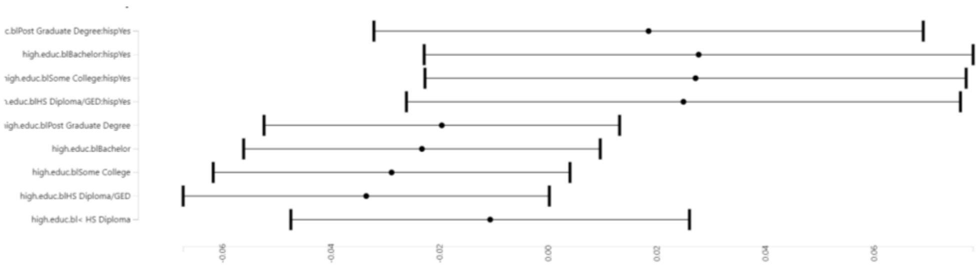
#p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001



Overall



by race



by ethnicity

Figure 1. Effects of Parental Education on Pre-adolescents Resting-state Functional Connectivity between CO and CP Networks Overall and by Race and Ethnicity

4. Discussion

We found a positive association between parental education and resting-state functional connectivity between the CO and CP networks. In line with the MDRs phenomenon, there were racial and ethnic differences in the associations between parental education and resting-state functional connectivity between the CO and CP networks. The correlation between parental education and resting-state functional connectivity between the CO and CP networks was larger for White and non-Hispanic children than Black and Hispanic children.

Our first finding aligns with the well-described effects of SES indicators, such as parental education on brain structure and function in adolescents and young people. However, most of this work has been conducted on single brain structures such as the hippocampus, cerebral cortex, thalamus, and amygdala [62,102-104]. High SES, for example, is linked to the activity of brain structures that correlate with emotion regulation and process [105]. Among children between 5 and 18 years old, family SES is associated with gray matter volume in the hippocampus [62] and hippocampus functional connectivity. In a cross-sectional study of 1,099 3-20-year-old children, parental education was associated with children's left hippocampal volume [50]. A strong relation is known between the number of years of parental education and the function and structure of the brain region involved in language, reading, social cognition, executive functions, and spatial skills [50]. Hanson et al. reported correlations between parental education and right hippocampal size [103]. However, very few studies to date have explored the relationship between parental education and resting-state functional connectivity between the CO and CP networks. One exception is a recent ABCD study that showed SES is linked to the CO-CP functional connectivity at rest [81]..

The association between parental education and resting-state functional connectivity between the CO and CP networks may be because parental education is a proxy of parents' low-risk behaviors [106] and high-quality parenting [107,108] as well as lower stress [109]. As such, parental education, parenting, and parental behaviors can substantially affect the brain development of children [32]. Indeed, parenting and home environment may be some vehicles by which parental education influences child development. In addition, parenting and parental quality are linked to children's behavior problems [110], psychopathologies [111], and cognitive performance [48,112].

In line with the MDRs, our second finding suggests that parental education is more strongly linked to resting-state functional connectivity between CO and CP networks for non-Hispanic and White children than Hispanic and Black children. Similar MDRs are reported for social and behavioral problems [113], attention [74], impulsivity and inhibitory control [114], ADHD [80], anxiety [115], depression [116], and suicidality [28] in Black and Hispanic adolescents.

Parental education and race and ethnicity have multiplicative rather than additive effects on resting-state functional connectivity between the CO and CP networks. Thereby, Black and Hispanic pre-adolescents, regardless of their SES, remain at high risk. Conversely, high parental education reduces the risk in non-Hispanic White pre-adolescents. Several MRI and behavioral studies, for example, provide evidence that hippocampus and associated areas are linked to attention deficit hyperactive disorder (ADHD) [117], intermittent explosive disorder [117], emotional disorder [118], bipolar depression [119], autism [120], schizotypal disorder [121], motor neuron disease [122], functional neurological disorders [123], memory [124,125], and executive function [126].

Several questions should be further addressed in future studies. First, it will be crucial for future research to explore societal conditions where parental education strongly affects pre-adolescents' brains across all racial and ethnic families. Such information may provide useful insights into new policies to reduce racial and ethnic disparities. To equalize racial and ethnic brain development, there is a need to equalize SES. However, there is also a need to equalize the marginal returns of SES. We need social and economic policies to deal with racial inequalities in brain development of middle-class Black and Hispanic families. Thus, policymakers should test policies that may equitably promote brain health for all people, regardless of their race and ethnic background. Elaboration of effective strategies requires a full understanding of underlying mechanisms for diminished returns of SES in Black and Hispanic families. Equity will not be achieved by closing the SES-based gaps across racial and ethnic groups. Social justice-promoting activities and policies are needed to equalize the returns of SES in different racial and ethnic minorities.

In this study, race and ethnicity were social rather than biological determinants. Race and ethnicity are social factors in all the MDRs literature, including studies on adolescents' brain development. Subsequently, racial and ethnic differences reported here have resulted from the differential treatment by society, which is preventable, not differences due to genes that are innate. Race and ethnicity here are proxies of racism, including labor market discrimination, low school quality, segregation, and differential policing, leading to the reduced effect of parental education, even for high SES and successful people who have secured economic and human resources. Thereby, the results should not be read as biological inferiority of any race or ethnic group due to genes [127].

5. Limitations

A few limitations should be mentioned before we can interpret our findings. First, a strong conclusion concerning the direction of the causal paths is limited in a cross-sectional design. Longitudinal studies are needed to fully understand how parental education, race, and their interactions impact changes and trajectories of brain function. Second, several SES indicators were not included here, which may change brain function and structure. These may include homeownership, wealth, and the occupational status of parents. Neighborhood-level SES indicators, such as home value, residential-area income, and area-level education level, were also not included. Third, the sample was not random. Thus, the results may not be generalizable to the entire population of US pre-adolescents. In addition, the sample was smaller for Black and Hispanic than White and non-Hispanic children. This is a common problem in almost all national studies. Finally, a wide range of relevant functional and structural features of the brain was not included. Behavioral manifestations were also not included.

6. Conclusions

Parental education shows stronger links for non-Hispanic and White pre-adolescents than for Hispanic and Black American pre-adolescents. These variations might be in part due to differences in the living experiences of racial and ethnic diverse groups of middle-class families, in line with the Marginalization-related Diminished Returns (MDRs). It will be crucial for future research to examine whether and how racism, social stratification, and segregation reduce the effects of parental education in Hispanic and Black communities compared to their White counterparts. It is yet unknown which social processes may contribute to a reduction of the benefit of SES indicators in Black and Hispanic communities.

ABCD Funding: Data came from the Adolescent Brain Cognitive Development (ABCD) Study. This is a multisite, longitudinal study designed to recruit more than 10,000 pre-adolescents aged 9-10 and follow them over 10 years into early adulthood. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/principal-investigators.html (accessed on 22 December 2020). ABCD consortium investigators designed and implemented the study and/or provided data but did not participate in the 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 2.0 under the doi: 10.15154/1503209 available here https://nda.nih.gov/abcd/query/abcd-curated-annual-release-2.0.html (accessed on 22 December 2020). The ABCD Study is supported by the National Institutes of Health Grants (U01DA041022, U01DA041028, U01DA041048, U01DA041089, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, U24DA041147). A full list of supporters is available at https://abcdstudy.org/nih-collaborators (accessed on 22 December 2020).

Author funding: Assari is supported by the NIH grants CA201415-02, U54CA229974, 5S21MD000103, 54MD008149, R25 MD007610, 2U54MD007598, 4P60MD006923, and U54 TR001627.

References

1. Ehrler, M., Latal, B., Kretschmar, O., von Rhein, M., & Tuura, R. O. G. (2020). Altered frontal white matter microstructure is associated with working memory impairments in adolescents with congenital heart disease: a diffusion tensor imaging study. *NeuroImage: Clinical*, *25*, 102123.
2. Lei, D., Li, L., Li, L., et al. (2015). Microstructural abnormalities in children with post-traumatic stress disorder: a diffusion tensor imaging study at 3.0 T. *Scientific Reports*, *5*(1), 1-6.
3. Mueller, B. A., Lim, K. O., Hemmy, L., & Camchong, J. (2015). Diffusion MRI and its role in neuropsychology. *Neuropsychology review*, *25*(3), 250-271.
4. Agorastos, A., Pervanidou, P., Chrousos, G. P., & Kolaitis, G. (2018). Early life stress and trauma: developmental neuroendocrine aspects of prolonged stress system dysregulation. *Hormones*, *17*(4), 507-520.
5. Basmacı Kandemir, S., Bayazıt, H., Selek, S., et al. (2016). Tracking down the footprints of bad paternal relationships in dissociative disorders: a diffusion tensor imaging study. *Journal of Trauma & Dissociation*, *17*(3), 371-381.
6. Butler, O., Yang, X. F., Laube, C., Kühn, S., & Immordino-Yang, M. H. (2018). Community violence exposure correlates with smaller gray matter volume and lower IQ in urban adolescents. *Human brain mapping*, *39*(5), 2088-2097.
7. Di Segni, M., Andolina, D., & Ventura, R. (2018). Long-term effects of early environment on the brain: lesson from rodent models. Paper presented at: Seminars in cell & developmental biology.
8. Sowell, E. R., Peterson, B. S., Thompson, P. M., Welcome, S. E., Henkenius, A. L., & Toga, A. W. (2003). Mapping cortical change across the human life span. *Nature neuroscience*, *6*(3), 309-315.
9. Albaugh, M. D., Hudziak, J. J., Ing, A., et al. (2019). White matter microstructure is associated with hyperactive/inattentive symptomatology and polygenic risk for attention-deficit/hyperactivity disorder in a population-based sample of adolescents. *Neuropsychopharmacology*, *44*(9), 1597-1603.
10. Ameis, S. H., Lerch, J. P., Taylor, M. J., et al. (2016). A diffusion tensor imaging study in children with ADHD, autism spectrum disorder, OCD, and matched controls: distinct and non-distinct white matter disruption and dimensional brain-behavior relationships. *American Journal of Psychiatry*, *173*(12), 1213-1222.
11. Di, X., Azeez, A., Li, X., Haque, E., & Biswal, B. B. (2018). Disrupted focal white matter integrity in autism spectrum disorder: a voxel-based meta-analysis of diffusion tensor imaging studies. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *82*, 242-248.
12. Gibbard, C. R., Ren, J., Skuse, D. H., Clayden, J. D., & Clark, C. A. (2018). Structural connectivity of the amygdala in young adults with autism spectrum disorder. *Human brain mapping*, *39*(3), 1270-1282.
13. da Rocha, J. L. D., Bramati, I., Coutinho, G., Moll, F. T., & Sitaram, R. (2020). Fractional Anisotropy changes in parahippocampal cingulum due to Alzheimer's Disease. *Scientific reports*,

10(1), 1-8.

14. Urger, S. E., De Bellis, M. D., Hooper, S. R., Woolley, D. P., Chen, S. D., & Provenzale, J. (2015). The superior longitudinal fasciculus in typically developing children and adolescents: diffusion tensor imaging and neuropsychological correlates. *Journal of child neurology*, *30*(1), 9-20.
15. Rosen, M. L., Sheridan, M. A., Sambrook, K. A., Meltzoff, A. N., & McLaughlin, K. A. (2018). Socioeconomic disparities in academic achievement: A multi-modal investigation of neural mechanisms in children and adolescents. *NeuroImage*, *173*, 298-310.
16. Ursache, A., Noble, K. G., Pediatric Imaging, N., & Study, G. (2016). Socioeconomic status, white matter, and executive function in children. *Brain and behavior*, *6*(10), e00531.
17. Novén, M., Olsson, H., Helms, G., Horne, M., Nilsson, M., & Roll, M. (2021). Cortical and white matter correlates of language-learning aptitudes. *Human Brain Mapping.* 2021.
18. Versace, A., Acuff, H., Bertocci, M. A. et al. (2015). White matter structure in youth with behavioral and emotional dysregulation disorders: a probabilistic tractographic study. *JAMA psychiatry*, *72*(4), 367-376.
19. Taylor, R. L., Cooper, S. R., Jackson, J. J., & Barch, D. M. (2020). Assessment of neighborhood poverty, cognitive function, and prefrontal and hippocampal volumes in children. *JAMA network open*, *3*(11), e2023774-e2023774.
20. Palacios-Barrios, E. E., & Hanson, J. L. (2019). Poverty and self-regulation: Connecting psychosocial processes, neurobiology, and the risk for psychopathology. *Comprehensive psychiatry*, *90*, 52-64.
21. Chan, M. Y., Na, J., Agres, P. F., Savalia, N. K., Park, D. C., & Wig, G. S. (2018). Socioeconomic status moderates age-related differences in the brain's functional network organization and anatomy across the adult lifespan. *Proceedings of the National Academy of Sciences*, *115*(22), E5144-E5153.
22. Hunt, J. F., Buckingham, W., Kim, A. J., et al. (2020). Association of neighborhood-level disadvantage with cerebral and hippocampal volume. *JAMA neurology*, *77*(4), 451-460.
23. Romeo, R. R., Segaran, J., Leonard, J. A. , et al. (2018). Language exposure relates to structural neural connectivity in childhood. *Journal of Neuroscience*, *38*(36), 7870-7877.
24. Farley, J. P., & Kim-Spoon, J. (2017). Parenting and adolescent self-regulation mediate between family socioeconomic status and adolescent adjustment. *The Journal of early adolescence*, *37*(4), 502-524.
25. Stevens, C., Lauinger, B., & Neville, H. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study. *Developmental science*, *12*(4), 634-646.
26. Farah, M. J. (2017). The neuroscience of socioeconomic status: Correlates, causes, and consequences. *Neuron*, *96*(1), 56-71.
27. Yaple, Z. A., & Yu, R. (2020). Functional and structural brain correlates of socioeconomic status.

Cerebral Cortex, *30*(1), 181-196.

28. Assari, S., Boyce, S., Bazargan, M., & Caldwell, C. H. (2020). 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.
29. Assari, S., & Boyce, S. (2021). Race, Socioeconomic Status, and Cerebellum Cortex Fractional Anisotropy in Pre-Adolescents. *Adolescents*, *1*(2), 70-94.
30. Jenkins, L. M., Chiang, J. J., Vause, K., et al. (2020). Subcortical structural variations associated with low socioeconomic status in adolescents. *Human brain mapping*, *41*(1), 162-171.
31. Assari, S., & Bazargan, M. (2019). Unequal effects of educational attainment on workplace exposure to second-hand smoke by race and ethnicity; minorities' diminished returns in the National Health Interview Survey (NHIS). *Journal of medical research and innovation*, *3*(2).
32. 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.
33. Gerra, G., Benedetti, E., Resce, G., Potente, R., Cutilli, A., & Molinaro, S. (2020). Socioeconomic status, parental education, school connectedness and individual socio-cultural resources in vulnerability for drug use among students. *International journal of environmental research and public health*, *17*(4), 1306.
34. Assari, S., Caldwell, C., & Bazargan, M. (2020). Parental educational attainment and relatives' substance use of American youth: Hispanics Diminished Returns. *Journal of biosciences and medicines*, *8*(2), 122.
35. 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.
36. Andrabi, N., Khoddam, R., & Leventhal, A. M. (2017). Socioeconomic disparities in adolescent substance use: Role of enjoyable alternative substance-free activities. *Social Science & Medicine*, 176, 175-182.
37. Assari, S., Mistry, R., Caldwell, C. H., & Bazargan, M. (2020). Protective effects of parental education against youth cigarette smoking: Diminished returns of Blacks and Hispanics. *Adolescent health, medicine and therapeutics*, *11*, 63.
38. Purnaningrum, W. D., Joebagio, H., & Murti, B. (2017). Association between cigarette advertisement, peer group, parental education, family income, and pocket money with smoking behavior among adolescents in Karanganyar District, Central Java. *Journal of health promotion and behavior*, *2*(2), 148-158.
39. Tuvblad, C., Grann, M., & Lichtenstein, P. (2006). Heritability for adolescent antisocial behavior differs with socioeconomic status: gene–environment interaction. *Journal of Child Psychology*

and Psychiatry, *47*(7), 734-743.

40. Cabello, R., Gutiérrez-Cobo, M. J., & Fernández-Berrocal, P. (2017). Parental education and aggressive behavior in children: a moderated-mediation model for inhibitory control and gender. *Frontiers in psychology*, *8*, 1181.
41. 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.
42. Holstein, B. E., Pant, S. W., Ammitzbøll, J., et al. (2021). Parental education, parent–child relations and diagnosed mental disorders in childhood: prospective child cohort study. *European Journal of Public Health*.
43. Reiss, F. (2013). Socioeconomic inequalities and mental health problems in children and adolescents: a systematic review. *Social science & medicine*, *90*, 24-31.
44. 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.
45. 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.
46. Assari, S. (2018). Life Expectancy Gain Due to Employment Status Depends on Race, Gender, Education, and Their Intersections. *J Racial Ethn Health Disparities*, *5*(2), 375-386.
47. Assari, S. (2020). College graduation and wealth accumulation: Blacks' diminished returns. *World journal of educational research*, *7*(3), 1.
48. Assari, S., Boyce, S., Bazargan, M., & Caldwell, C. H. (2020). Diminished Returns of Parental Education in Terms of Youth School Performance: Ruling out Regression toward the Mean. *Children*, *7*(7), 74.
49. Assari, S. (2020). Parental education and spanking of American children: Blacks' diminished returns. *World journal of educational research*, *7*(3), 19.
50. Noble, K. G., Houston, S. M., Brito, N. H., et al. (2015). Family income, parental education and brain structure in children and adolescents. *Nature neuroscience*, *18*(5), 773.
51. Hagadorn, M. A., Johnson, M. M., Smith, A. R., Seid, M. A., & Kapheim, K. M. (2021). Experience, but not age, is associated with volumetric mushroom body expansion in solitary alkali bees. *Journal of Experimental Biology*, *224*(6), jeb238899.
52. Kim, D.-J., Davis, E. P., Sandman, C. A., et al. (2019). Childhood poverty and the organization of structural brain connectome. *Neuroimage*, 184, 409-416.
53. Lawson, G. M., Camins, J. S., Wisse, L., et al. (2017). Childhood socioeconomic status and childhood maltreatment: Distinct associations with brain structure. *PloS one*, *12*(4), e0175690.
54. Raznahan, A., Shaw, P., Lalonde, F., et al. (2011). How does your cortex grow? *Journal of Neuroscience*, *31*(19), 7174-7177.

55. Gold, A. L., Steuber, E. R., White, L. K., et al. (2017). Cortical thickness and subcortical gray matter volume in pediatric anxiety disorders. *Neuropsychopharmacology*, *42*(12), 2423-2433.
56. Philby, M. F., Macey, P. M., Ma, R. A., Kumar, R., Gozal, D., & Kheirandish-Gozal, L. (2017). Reduced regional grey matter volumes in pediatric obstructive sleep apnea. *Scientific reports*, *7*(1), 1-9.
57. Esteban-Cornejo, I., Cadenas-Sanchez, C., Contreras-Rodriguez, O., et al. (2017). A whole brain volumetric approach in overweight/obese children: Examining the association with different physical fitness components and academic performance. The ActiveBrains project. *Neuroimage*, *159*, 346-354.
58. Merz, E. C., Desai, P. M., Maskus, E. A., et al. (2019). Socioeconomic disparities in chronic physiologic stress are associated with brain structure in children. *Biological psychiatry*, *86*(12), 921-929.
59. Boedhoe, P. S., Van Rooij, D., Hoogman, M., et al. (2020). Subcortical brain volume, regional cortical thickness, and cortical surface area across disorders: Findings from the ENIGMA ADHD, ASD, and OCD working groups. *American Journal of Psychiatry*, *177*(9), 834-843.
60. Murphy, M., Whitton, A. E., Deccy, S., et al. (2020). Abnormalities in electroencephalographic microstates are state and trait markers of major depressive disorder. *Neuropsychopharmacology*, *45*(12), 2030-2037.
61. Semrud-Clikeman, M., Fine, J. G., Bledsoe, J., & Zhu, D. C. (2013). Magnetic resonance imaging volumetric findings in children with Asperger syndrome, nonverbal learning disability, or healthy controls. *J Clin Exp Neuropsychol*, *35*(5), 540-550.
62. Noble, K. G., Houston, S. M., Kan, E., & Sowell, E. R. (2012). Neural correlates of socioeconomic status in the developing human brain. *Developmental science*, *15*(4), 516-527.
63. Dubois, J., & Adolphs, R. (2016). Building a science of individual differences from fMRI. *Trends in cognitive sciences*, *20*(6), 425-443.
64. Javanbakht, A., Kim, P., Swain, J. E., Evans, G. W., Phan, K. L., & Liberzon, I. (2016). Sex-specific effects of childhood poverty on neurocircuitry of processing of emotional cues: a neuroimaging study. *Behavioral Sciences*, *6*(4), 28.
65. Evans, G. W., Swain, J. E., King, A. P., et al. (2016). Childhood cumulative risk exposure and adult amygdala volume and function. *Journal of Neuroscience Research*, *94*(6), 535-543.
66. Javanbakht, A., King, A. P., Evans, G. W., et al. (2015). Childhood poverty predicts adult amygdala and frontal activity and connectivity in response to emotional faces. *Frontiers in behavioral neuroscience*, *9*, 154.
67. Assari, S. (2021). Parental Education and Children’s Sleep Problems: Minorities’ Diminished Returns. *International Journal of Epidemiologic Research*, *8*(1), 31-39.
68. Assari, S., & Boyce, S. (2021). Family's Subjective Economic Status and Children's Matrix Reasoning: Blacks' Diminished Returns. *Res Health Sci.*, *6*(1), 1-23.

69. Assari, S., Boyce, S., Bazargan, M., et al. (2021). Parental Educational Attainment, the Superior Temporal Cortical Surface Area, and Reading Ability among American Children: A Test of Marginalization-Related Diminished Returns. *Children*, *8*(5), 412.
70. Assari, S., Boyce, S., & Bazargan, M. (2020). Subjective socioeconomic status and children's amygdala volume: Minorities' diminish returns. *NeuroSci.*, *1*(2), 59-74.
71. Dotson, V. M., Kitner-Triolo, M. H., Evans, M. K., & Zonderman, A. B. (2009). Effects of race and socioeconomic status on the relative influence of education and literacy on cognitive functioning. *Journal of the International Neuropsychological Society*, *15*(4), 580-589.
72. Assari, S. (2018). Health disparities due to diminished return among black Americans: Public policy solutions.
73. Assari, S., & Caldwell, C. H. (2018). High risk of depression in high-income African American boys. *Journal of racial and ethnic health disparities*, *5*(4), 808-819.
74. Assari, S., Boyce, S., & Bazargan, M. (2020). Subjective Family Socioeconomic Status and Adolescents' Attention: Blacks' Diminished Returns. *Children*, *7*(8), 80.
75. Assari, S., Caldwell, C. H., & Zimmerman, M. A. (2018). Depressive Symptoms During Adolescence Predict Adulthood Obesity Among Black Females. *J Racial Ethn Health Disparities*, *5*(4), 774-781.
76. 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.
77. Boyce, S., Bazargan, M., Caldwell, C. H., Zimmerman, M. A., & Assari, S. (2020). Parental educational attainment and social environment of urban public schools in the US: Blacks' diminished returns. *Children*, *7*(5), 44.
78. Assari, S., & Islam, S. (2020). Diminished Protective Effects of Household Income on Internalizing Symptoms among African American than European American Pre-Adolescents. *Journal of economics, trade and marketing management*, *2*(4), 38.
79. Assari, S., & Jeremiah, R. D. (2018). Intimate Partner Violence May Be One Mechanism by Which Male Partner Socioeconomic Status and Substance Use Affect Female Partner Health. *Front Psychiatry*, *9*, 160.
80. Assari, S., & Caldwell, C. H. (2019). Family income at birth and risk of attention deficit hyperactivity disorder at age 15: racial differences. *Children*, *6*(1), 10.
81. 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*, 101005.
82. 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.

83. Gilbert, K. E., Wheelock, M. D., Kandala, S., Eggebrecht, A. T., Luby, J. L., & Barch, D. M. (2021). Associations of observed preschool performance monitoring with brain functional connectivity in adolescence. *Cortex*.
84. Bush, G., & Shin, L. M. (2006). The Multi-Source Interference Task: an fMRI task that reliably activates the cingulo-frontal-parietal cognitive/attention network. *Nature protocols*, *1*(1), 308-313.
85. Bush, G. (2011). Cingulate, frontal, and parietal cortical dysfunction in attention-deficit/hyperactivity disorder. *Biological psychiatry*, *69*(12), 1160-1167.
86. Research, A., & Staff, C. R. E. (2018). NIH's Adolescent Brain Cognitive Development (ABCD) Study. *Alcohol research: current reviews*, *39*(1), 97.
87. Casey, B., Cannonier, T., Conley, M. I., et al. (2018). The adolescent brain cognitive development (ABCD) study: imaging acquisition across 21 sites. *Developmental cognitive neuroscience*, *32*, 43-54.
88. Lisdahl, K. M., Sher, K. J., Conway, K. P., et al. (2018). Adolescent brain cognitive development (ABCD) study: Overview of substance use assessment methods. *Developmental cognitive neuroscience*, *32*, 80-96.
89. Luciana, M., Bjork, J., Nagel, B., et al. (2018). Adolescent neurocognitive development and impacts of substance use: Overview of the adolescent brain cognitive development (ABCD) baseline neurocognition battery. *Developmental cognitive neuroscience*, *32*, 67-79.
90. Lisdahl, K. M., Sher, K. J., Conway, K. P., et al. (2020). Adolescent brain cognitive development (ABCD) study: Overview of substance use assessment methods: Erratum. 2020.
91. Auchter, A. M., Mejia, M. H., Heyser, C. J., et al. (2018). A description of the ABCD organizational structure and communication framework. *Developmental cognitive neuroscience*, *32*, 8-15.
92. Garavan, H., Bartsch, H., Conway, K., et al. (2018). Recruiting the ABCD sample: Design considerations and procedures. *Developmental cognitive neuroscience*, *32*, 16-22.
93. Ewing, S. W. F., Bjork, J. M., & Luciana, M. (2018). Implications of the ABCD study for developmental neuroscience. *Developmental cognitive neuroscience*, *32*, 161-164.
94. Hagler, Jr. D. J., Hatton, S., Cornejo, M. D., et al. (2019). Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *Neuroimage*, *202*, 116091.
95. Jovicich, J., Czanner, S., Greve, D., et al. (2006). Reliability in multi-site structural MRI studies: effects of gradient non-linearity correction on phantom and human data. *Neuroimage*, *30*(2), 436-443.
96. 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.
97. 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.

98. 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.

99. Gordon, E. M., Laumann, T. O., Adeyemo, B., Huckins, J. F., Kelley, W. M., & Petersen, S. E. (2016). Generation and evaluation of a cortical area parcellation from resting-state correlations. *Cerebral cortex*, *26*(1), 288-303.

100. Hagler, D. J., Jr., Hatton, S., Cornejo, M. D., et al. (2019). Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *Neuroimage*, *202*, 116091.

101. Casey, B. J., Cannonier, T., Conley, M. I., et al. (2018). The Adolescent Brain Cognitive Development (ABCD) study: Imaging acquisition across 21 sites. *Dev Cogn Neurosci*, *32*, 43-54.

102. Jednoróg, K., Altarelli, I., Monzalvo, K., et al. (2012). The influence of socioeconomic status on children’s brain structure.

103. Hanson, J. L., Chandra, A., Wolfe, B. L., & Pollak, S. D. (2011). Association between income and the hippocampus. *PloS one*, *6*(5), e18712.

104. 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.

105. Muscatell, K. A., Morelli, S. A., Falk, E. B., et al. (2012). Social status modulates neural activity in the mentalizing network. *Neuroimage*, *60*(3), 1771-1777.

106. Spann, S. J., Gillespie, C. F., Davis, J. S., et al. (2014). The association between childhood trauma and lipid levels in an adult low-income, minority population. *General hospital psychiatry*, *36*(2), 150-155.

107. Woods-Jaeger, B. A., Cho, B., Sexton, C. C., Slagel, L., & Goggin, K. (2018). Promoting resilience: Breaking the intergenerational cycle of adverse childhood experiences. *Health Education & Behavior*, *45*(5), 772-780.

108. Anton, M. T., Jones, D. J., & Youngstrom, E. A. (2015). Socioeconomic status, parenting, and externalizing problems in African American single-mother homes: A person-oriented approach. *Journal of Family Psychology*, *29*(3), 405.

109. Parkes, A., Sweeting, H., & Wight, D. (2015). Parenting stress and parent support among mothers with high and low education. *Journal of Family Psychology*, *29*(6), 907.

110. Choi, J.-K., Wang, D., & Jackson, A. P. (2019). Adverse experiences in early childhood and their longitudinal impact on later behavioral problems of children living in poverty. *Child abuse & neglect*, *98*, 104181.

111. Padilla-Moledo, C., Ruiz, J., & Castro-Piñero, J. (2016). Parental educational level and psychological positive health and health complaints in Spanish children and adolescents. *Child: care, health and development*, *42*(4), 534-543.

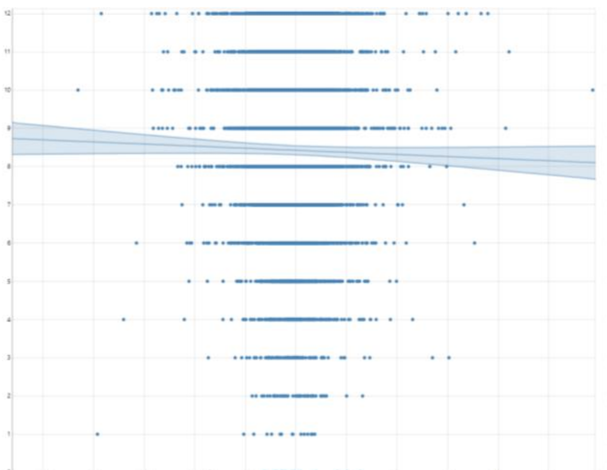
112. Assari, S., & Caldwell, C. H. (2019). Parental educational attainment differentially boosts school performance of American adolescents: Minorities’ diminished returns. *Journal of family &*

reproductive health, *13*(1), 7.

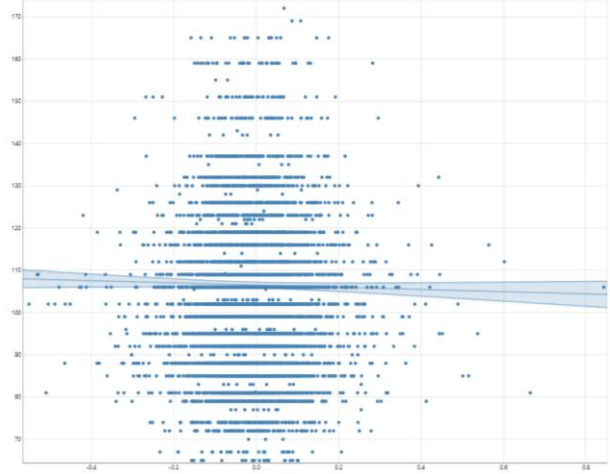
113. Assari, S., & Boyce, S. (2020). Family's Subjective Economic Status and Children's Matrix Reasoning: Blacks' Diminished Returns. *Research in Health Science*, *6*(1), 1-23.
114. Assari, S., Caldwell, C. H., & Mincy, R. (2018). Family socioeconomic status at birth and youth impulsivity at age 15; Blacks' diminished return. *Children*, *5*(5), 58.
115. Assari, S., Caldwell, C. H., & Zimmerman, M. A. (2018). Family structure and subsequent anxiety symptoms; minorities' diminished return. *Brain sciences*, *8*(6), 97.
116. Assari, S., Gibbons, F. X., & Simons, R. (2018). Depression among black youth; interaction of class and place. *Brain sciences*, *8*(6), 108.
117. Puiu, A. A., Wudarczyk, O., Goerlich, K. S., et al. (2018). Impulsive aggression and response inhibition in attention-deficit/hyperactivity disorder and disruptive behavioral disorders: Findings from a systematic review. *Neuroscience & biobehavioral reviews*, *90*, 231-246.
118. Schmahmann, J. D. (2021). Emotional disorders and the cerebellum: Neurobiological substrates, neuropsychiatry, and therapeutic implications. In: *Handbook of Clinical Neurology.* Vol 183. Elsevier; 2021:109-154.
119. Poletti, S., Leone, G., Hoogenboezem, T. A., et al. (2019). Markers of neuroinflammation influence measures of cortical thickness in bipolar depression. *Psychiatry Research: Neuroimaging*, *285*, 64-66.
120. Pereira, A. M., Campos, B. M., Coan, A. C., et al. (2018). Differences in cortical structure and functional MRI connectivity in high functioning autism. *Frontiers in neurology*, *9*, 539.
121. Takayanagi, Y., Sasabayashi, D., Takahashi, T., et al. (2020). Reduced cortical thickness in schizophrenia and schizotypal disorder. *Schizophrenia bulletin*, *46*(2), 387-394.
122. Machts, J., Keute, M., Kaufmann, J., et al. (2021). Longitudinal clinical and neuroanatomical correlates of memory impairment in motor neuron disease. *NeuroImage: Clinical*, *29*, 102545.
123. Williams, B., Jalilianhasanpour, R., Matin, N., et al. (2018). Individual differences in corticolimbic structural profiles linked to insecure attachment and coping styles in motor functional neurological disorders. *Journal of psychiatric research*, *102*, 230-237.
124. Kumar, U., Singh, A., & Paddakanya, P. (2021). Extensive long-term verbal memory training is associated with brain plasticity. *Scientific reports*, *11*(1), 1-12.
125. Brehmer, Y., Nilsson, J., Berggren, R., Schmiedek, F., & Lövdén, M. (2020). The importance of the ventromedial prefrontal cortex for associative memory in older adults: a latent structural equation analysis. *NeuroImage*, *209*, 116475.
126. Weise, C. M., Bachmann, T., Schroeter, M. L., & Saur, D. (2019). When less is more: Structural correlates of core executive functions in young adults–A VBM and cortical thickness study. *Neuroimage*, *189*, 896-903.
127. Herrnstein, R. J., & Murray, C. (2010). *The bell curve: Intelligence and class structure in American life.* Simon and Schuster.

Supplementary Table 1. Model formula in DEAP

Model 1
rsfmri_cor_network.gordon_cinguloparietal_network.gordon_cinguloopercc ~ high.educ.bl + race.4level + hisp + sex + married.bl + age Random: ~(1|rel_family_id)
Model 2
rsfmri_cor_network.gordon_cinguloparietal_network.gordon_cinguloopercc ~ high.educ.bl + race.4level + hisp + sex + married.bl + age + high.educ.bl * race.4level Random: ~(1|rel_family_id)
Model 3
rsfmri_cor_network.gordon_cinguloparietal_network.gordon_cinguloopercc ~ high.educ.bl + race.4level + hisp + sex + married.bl + age + high.educ.bl * hisp Random: ~(1|rel_family_id)



Correlation between CP CO functional connectivity and reward responsiveness (bisbas_ss_basm_rr) (y axis)



Correlation between CP CO functional connectivity and memory/executive function (nihtbx_picture_agecorrected) (y axis)

Figure Appendix: Validation of CP CO functional connectivity