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Racism May Weaken the Brain-Behavior Association among African American Children: The Case of Amygdala Volume-Emotion Regulation Link

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Abstract

Introduction: The amygdala has a central core role in regulating emotions. However, less is known about the racial/ethnic variation in the relevance of amygdala volume for emotion regulation of US children. According to the Minorities' Diminished Returns (MDRs) phenomenon, due to racism, segregation, and social stratification (rather than innate differences due to genetics), some of the individual-level individual social determinants, could lose some of their relevance for African American (in comparison to White) children.

Purpose: Conceptualizing race as a social factor that reflects structural racism and discrimination and building on the MDRs framework, we explored racial variation in the magnitude of the association between amygdala volume and emotion regulation/impulsivity of US children.

Methods: For this cross-sectional study, we used baseline data which included behavioral, social, and structural magnetic resonance imaging (MRI) data of 6030 US children ages 9-10. Data came from the Adolescent Brain Cognitive Development (ABCD) study. The primary outcomes were positive and negative urgency. These were measured using Urgency, Premeditation (lack of), Perseverance (lack of), Sensation Seeking, Positive Urgency, and Impulsive Behavior Scale (UPPS-SS) UPPS-SS. The independent variables were right and left amygdala volume. The covariates were age, sex, parental education, household income, parental marital status, neighborhood socioeconomic status, and ethnicity. Race was the moderator.

Results: Children with larger amygdala volumes had lower positive and negative urgency. The correlations between amygdala volume and positive and negative urgency were modified by race. For White children, children had better emotion regulation when they had a large amygdala. For African American children, positive and negative urgency did not show an association with amygdala size.

Conclusions: The results can be explained by the Minorities' Diminished Returns (MDRs) hypothesis. In line with MDRs and as a result of structural and interpersonal inequalities, such as school segregation, the amygdala-emotion regulation seen for White children does not replicate for African American children. For White children, however, in the absence of higher-level social determinants, amygdala size correlates with emotion regulation. The brain-behavior link is weaker for African American children whose lives are less predictable and affected by experiences of racial discrimination. Unequal effects of equal resources across racial groups are due to racism and discrimination, not biological innate differences such as genetics.

Keywords: Amygdala; Limbic System; Children; MRI; Population groups; Emotion Regulation; Impulse Control; Inhibitory Control

Introduction

The right and left amygdala, almond-like structures [1], located deep in the brain's medial temporal lobe of each hemisphere, are core elements of the limbic system and play a major role in emotion processing and regulation [2-9]. For humans and animals, the right and left amygdala modulate all reactions to emotionally charged events and sensory input [2]. The role of the amygdala in regulating human emotions and behaviors is well-described [10-13]. This subcortical brain structure processes emotionally charged, rewarding, and or threatening environmental inputs and stimuli [14] and has a major role in emotions [1]. Although the amygdala is best known for its role in processing fear and threat, it also has a role in emotion regulation, inhibitory control, and decision making [15]. While changes of the amygdala are best known in anxiety disorders such as general anxiety disorder (GAD), post-traumatic stress disorder (PTSD) [4-6,16],

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phobias and panic disorder (PD) [17], altered amygdala function and size is shown for other disorders and problem such as autism, schizophrenia [18,19], aggression [20,21] and depression [22].

The amygdala size- emotion regulation is well described in the neuroscience literature [23]. As a result, youth and adults with a smaller amygdala are at an increased risk of mood disorders [24] such as bipolar disorder [25] and depression [22,26]. In most disorders mentioned above, the amygdala is small but hyperactive [24,27]. It is, however, unknown if behavioral correlation of amygdala size differs across population sub-groups, particularly those racialized as White and African American [28].

Race, which can closely overlap with socioeconomic status (SES) and chronic stress, can serve as a proxy of exposure to racism and other environmental factors that may impact various brain structures including the amygdala [29-32]. Race impacts amygdala and other brain structures, because racial/ethnic minority populations are chronically exposed to various forms of discrimination, stress, and economic disadvantages [33]. Thus; some of the race effects on the brain can be a function of the experiences associated with SES, particularly at the lower end especially in the case of poverty like experiences [33]. However, the SES effects on brain may also vary by race. Some studies have shown that SES effects on shaping some brain structures may be more robust for low SES children [33]. Due to racism, discrimination, and segregation, however, racial minority groups may not show the effects of SES on brain [34]. This is recently described as racism-related diminished returns of SES on children's brain development [35,36].

Minorities' Diminished Returns (MDRs) have been shown?? To have weaker SES effects for African Americans than White individuals. These MDRs emerge because high SES African American families have lower household income and wealth and experience higher levels of stress and discrimination [37-41]. As a result of residential segregation, moderate to high SES African American children can remain with high-risk peers [42] and in high-risk schools [43] and neighborhoods [44]. Similarly, moderate to high SES African American children still experience high levels of chronic stress [44-46], which have been shown to hinder their healthy brain development [8,47-49]. Similar MDRs are shown for the effects of SES on trauma [46], ADHD [50], suicide [51], depression [52], anxiety [53], aggression [54], tobacco use [54-56], impulsivity [57], school bonding [58], school performance [59], and inhibitory control [60]. All these SES effects are stronger in White than African American youth. These African American-White differences in the SES effects (i.e., MDRs) are frequently replicated [41,61-63], suggesting that weakened effect of SES in African American than White children is a robust phenomenon [61]. In this view, family-level SES have smaller than expected effects on shaping African American children's brain development [50,63-68]. That means it is related to the social structural -level barriers (e.g., segregation) and interpersonal stressors (e.g., discrimination) that SES resources lose some of their effects for African Americans when compared to Whites [61]. For example, due to experiences like labor market discrimination, segregation, and racism, experiences of high-SES and low-SES African American families are more similar [61] than among high-SES and low-SES White families [37]. This is partly because SES can be more protective for populations which do not face chronic forms of race-based discrimination (e.g., American Whites) [38,69].

In the Adolescent Brain Cognitive Development (ABCD) study [70-73], family SES increased the amygdala size for White children but not African American children [34]. Similar patterns were observed for the thalamus [74], hippocampus [75], cerebral cortex [76,77], and cerebellum [78]. In another paper, SES showed stronger effects on brain structure and function in White people than African American people [79].

MDRs, however, are not limited to SES. Not only economic but also non-economic resources and assets lose some of their beneficial or protective effects in African Americans than Whites [63,80,81]. For example, age, emotion regulation, self-efficacy, and coping show larger positive health consequences for Whites than African Americans [82-89]. In the same manner that SES indicators have weaker effects on positive health outcomes for African Americans than Whites. As a function of racism and discrimination, brain mechanisms and how brain structures function under these conditions may have weaker effects on behavioral and physical health outcomes for African Americans than White communities [38,90].

Aims

Employing data from the ABCD study and the MDRs framework, we used the behavioral [54] and brain imaging data [34] to investigate the differential effect of amygdala size on positive/negative urgency of 9-10 years old American children. Our first hypothesis was an inverse association between amygdala size and positive/negative urgency of the children. Our second hypothesis was a weaker association between amygdala size and positive/negative urgency as a proxy of emotion regulation and impulsivity for African American than White children. In other words, we expect high levels of positive/negative urgency for African American children regardless of the child's amygdala size. For White children, however, our prediction is an inverse association between amygdala size and positive/negative urgency (as a proxy of emotion regulation and impulsivity).

Methods

Design and settings

This was a secondary analysis of wave 1 of the Adolescent Brain Cognitive Development (ABCD) study [70-73]. The ABCD is national existing data of brain imaging and child development. The ABCD data was borrowed from the NDA website. The ABCD is a landmark brain development study of United States youth. Detailed information on the ABCD methods, sampling, sample, measures, and imaging techniques are available here [70-73,91,92].

Participants and sampling

The ABCD participants were 9-10 children, who were between ages 9 and 11 years. Children in the ABCD study were recruited from multiple cities across multiple states. Overall, participants were enrolled from 21 different sites. The primary source of recruitment for the ABCD sample was US school systems. The sampling protocol of the ABCD study is described in detail here [70]. In the specific analysis, our sample was composed of a total number of 6030 9-10-year-old participants who were either White or African American. Our analysis's eligibility included valid data on race, ethnicity, demographics, parental education, parental marital status, amygdala volume, and positive and negative urgency.

Study variables

Amygdala volume: The independent variables were the right and the left amygdala volume (mm^3), measured by structural MRI at rest, as described here [93].

Moderator

Race: Race was self-identified by the parent. Race was a dichotomous variable: African American and White (reference category).

Outcomes: Outcomes were positive and negative urgency. These were measured using the Urgency, Premeditation (lack of), Perseverance (lack of), Sensation Seeking, Positive Urgency, Impulsive Behavior Scale (UPPS-SS) UPPS-SS. Positive and negative urgency are correlated constructs that reflect two inter-related aspects of impulsivity. Positive urgency is the inability to wait and postpone reward. Negative urgency is the inability to tolerate negative input. In this study, positive urgency was treated as a continuous measure, with a higher score indicating higher positive urgency traits (higher impulsivity). The UPPS-SS is a valid and reliable measure [94-100]. These constructs have shown reliability and validity in past research [101-103].

Age, sex, ethnicity, household income, parental education, neighborhood SES, and parental marital status were the confounding variables. Ethnicity was measured by the self-identification of the parents. Ethnicity was a dichotomous variable and coded 1 for Latino and 0 for non-Latino (reference category) families. Parents reported children's age which was calculated as months passed since birth. Sex of the child was a dichotomous variable that was coded 0 for males and 1 for females. Parental educational attainment was an ordinal variable: less than high school (reference category), high school, college, graduate + school. Parental marital status was also a dichotomous variable, self-reported by the parent interviewed, and coded 1 *vs.* 0 for married and unmarried families respectively. Parental education was a continuous measure reflecting years of schooling. Household income was a continuous measure ranging from 1 to 10, with a higher score indicating higher SES. We also used Area Deprivation Index (Neighborhood disorder) [104] as the measure of social context.

Data analysis

We used SS 25.0 for data analysis. The primary outcomes were positive and negative urgency. The independent variables were right and left amygdala volume. Covariates were age, sex, parental marital status, parental education, Area Deprivation Index (Neighborhood disorder) [104], and ethnicity. Model 1 tested the additive effects of amygdala size and race, with the same covariates, without interaction terms. Model 2 tested the interaction between amygdala size and race with all covariates. We ran identical models for the right and left amygdala and positive and negative urgency. Before running our models, we checked a wide range of assumptions, including normal distribution of our outcomes, lack of collinearity between predictors and covariates, and the distribution of errors for our models.

Ethical aspect

Our secondary analysis was found by the Charles R Drew University of Medicine and Science (CDU) Institutional Review Board (IRB) to be exempt from a full IRB review. However, the original ABCD study underwent an Institutional Review Board (IRB) in several institutions, including but not limited to the University of California, San Diego (UCSD). The IRB in multiple institutions approved the ABCD study protocol, and all of the children provided assent, and the parents signed consent.

Results

Sample descriptive data

Table 1 shows descriptive data overall. This study included 6030 children who were 9-10 year of age. From this number, 75.6% were White, and 24.4% were African American. Table 1 also compared study variables by race. African American and White children did not differ in age or sex, but they differed in Hispanic ethnicity, positive and negative urgency, SES, and right and left amygdala volume (size).

Regressions

Positive urgency: As shown by Table 2, the right and left amygdala size affected positive urgency when all confounders were controlled. However, the protective effect of children's right amygdala size on positive urgency was smaller in African Americans than in White children.

Negative urgency: As shown by Table 3, the right and left amygdala size affected negative urgency when all confounders were controlled. However, the protective effects of children's right and left amygdala size on negative urgency were smaller in African American children than in White children.

Discussion

Overall, we found inverse associations between the right and left amygdala size and positive and negative urgency as a proxy of impulsivity of Black and White US children. However, the links between amygdala volume and impulsivity were weaker for African American children than for White children. This was shown by statistical interactions between children's amygdala size and race on indicators of impulsivity. This provides an example of African American children's relative disadvantage compared to White children in the behavioral returns of their amygdala size (brain-behavior link).

Our observed results (statistical interactions) are in line with the Minorities' Diminished Returns (MDRs) framework. As explained by the MDRs framework, due to structural inequalities, segregation, and even interpersonal discrimination, an increase in amygdala size would not result in the same level of favorable behavior for African American children compared to White children. This is also described as racism-related unequal effects of equal resources across racial groups [105,106].

Larger amygdala size in children was associated with less impulsivity (urgency). However, this gain was larger for White children than for African American children. The brain-behavior link is well established [101-103,107,108]. Brain measures including amygdala volume correlate with emotional, behavioral, and cognitive function [109-111]. However, the environment – brain-behavior link may vary across social groups [112].

Table 1: Descriptive statistics in the pooled sample by race.

	All		African American		White	
	n	%	n	%	n	%
Race						
White	4558	75.6	-	-	4558	100
AA	1472	24.4	1472	100	-	-
Ethnicity						
Non	5044	83.6	1346	91.4	3698	81.1
Latino*	986	16.4	126	8.6	860	18.9
Sex						
Female	2633	43.7	684	46.5	1949	42.8
Male	3397	56.3	788	53.5	2609	57.2
Puberty*						
Pre	1634	27.1	280	19	1354	29.7
None	4396	72.9	1192	81	3204	70.3
Married Family*						
No	1946	32.3	974	66.2	972	21.3
Yes	4084	67.7	498	33.8	3586	78.7
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age	9.4951	0.50843	9.486	0.5137	9.498	0.50674
Residential history derived - Area Deprivation Index (based on Kind et al., Annals of Internal Medicine, 2014)*	93.56	24.408	104.86	21.825	89.9	24.078
Parental Education*	16.7706	2.56602	15.3988	2.57596	17.2137	2.40108
Financial Difficulty*	0.0687	0.16051	0.1446	0.21859	0.0442	0.1273
Amygdala Volume (Right)/1000*	1.6179	0.2266	1.5499	0.21269	1.6399	0.22661
Amygdala Volume (Left)/1000*	1.5757	0.23124	1.4955	0.21234	1.6016	0.23116
Positive Urgency*	7.98	2.944	8.57	3.207	7.78	2.828
Negative Urgency*	8.52	2.645	8.81	2.859	8.42	2.565

*p<0.001 for comparison of African American and White children.

Our second finding is that change in amygdala size is linked to a smaller improvement in expected behaviors for African Americans than Whites. This is well described as MDRs [105,106]. In the Adolescent Brain Cognitive Development (ABCD) [51,60,64,113], Add Health [114], Fragile Families and Child Wellbeing Study (FFCWS) [50,57,58,115-118], Monitoring the Future (MTF) [59], National Survey of American Life (NSAL) [52], Flint Adolescents Study (FAS) [53], and Family and Community Health Study (FACHS) [119,120] data sets, age, SES indicators, and other resources and assets generate fewer developmental outcomes for African American and other ethnic minorities than for Whites. For example, high SES shows a larger effect on depression [52], anxiety [53], aggression [54], tobacco use [56], school attachment [58], school performance [59], attention deficit hyperactivity disorder (ADHD) [50], impulsivity [57], inhibitory control [121], stress [46,115], obesity [118], and physical health [54] for White children than for African American children. This is in part because individual-level resources and assets do not reflect the very same t phenomenon across contexts. The same resource can do much less for marginalized group in highly segregated poverty-driven urban areas than highly-resourced suburban context.

The most closely relevant MDRs research findings is a recent study that showed a diminished effect of children's amygdala size on teachers' reported behavioral problems of African American children. The paper used the ABCD study and showed that the relevance of the amygdala for teacher reports of the behavioral problem was diminished for African American than White children [122]. Another study showed diminished effects of age on inhibitory control. Other papers reported weaker effects of positive and negative urgency on suicidality [123] and obesity [123] for African American children than for White children.

To give other research support of the role of MDRs, we found a higher prevalence of depression in high SES African American children and adults [52,119,120,124-126]. In Flint, Michigan, White children from married families were protected against future symptoms of anxiety; however, this was not the case for African American children, whose family structure did not protect against subsequent anxiety symptoms [53]. In the Fragile Families and Child Wellbeing Study (FFCWS), which followed a sample of African American and White children from birth to age 15, family SES at birth better improved mental and physical health of White than African American children at age 15 [57,118,127]. White but not Black children from high SES families were protected against ADHD [50]. In the Population Assessment of Tobacco and Health (PATH) data, high-SES African American children remain at risk of

Table 2: Association between amygdala volume and positive urgency.

	Model 1						Model 2					
	b	SE	Beta	95%CI		p	b	SE	Beta	95%CI		p
Right												
Race (AA)	0.336	0.102	0.049	0.137	0.536	0.001	-1.241	0.64	-0.181	-2.496	0.014	0.053
Ethnicity (Hispanic)	-0.081	0.105	-0.01	-0.288	0.125	0.439	-0.089	0.105	-0.011	-0.295	0.118	0.399
Age (Yr)	-0.148	0.074	-0.025	-0.292	-0.003	0.046	-0.145	0.074	-0.025	-0.29	-0.001	0.049
Male	0.58	0.08	0.098	0.423	0.736	0	0.579	0.08	0.098	0.423	0.735	0
Puberty	0.349	0.085	0.053	0.182	0.516	0	0.351	0.085	0.053	0.185	0.518	0
Married	-0.185	0.092	-0.029	-0.365	-0.005	0.044	-0.189	0.092	-0.03	-0.37	-0.009	0.039
Area Deprivation Index (Kind 2014)	0.004	0.002	0.029	0	0.007	0.032	0.004	0.002	0.03	0	0.007	0.029
Parental Education	-0.078	0.017	-0.068	-0.111	-0.045	0	-0.077	0.017	-0.067	-0.11	-0.044	0
Financial Difficulty	0.996	0.251	0.054	0.505	1.487	0	1.004	0.251	0.055	0.513	1.495	0
Right Amygdala Volume/1000	-0.467	0.177	-0.036	-0.815	-0.12	0.008	-0.689	0.198	-0.053	-1.078	-0.3	0.001
Right Amygdala Volume/1000 x Race (AA)							1.003	0.402	0.23	0.215	1.79	0.013
Left												
Race (AA)	0.323	0.102	0.047	0.123	0.523	0.002	-0.288	0.62	-0.042	-1.503	0.927	0.642
Ethnicity (Hispanic)	-0.091	0.105	-0.011	-0.297	0.116	0.389	-0.096	0.105	-0.012	-0.302	0.111	0.364
Age (Yr)	-0.14	0.074	-0.024	-0.285	0.004	0.057	-0.141	0.074	-0.024	-0.286	0.004	0.057
Male	0.589	0.079	0.099	0.433	0.745	0	0.589	0.079	0.099	0.433	0.745	0
Puberty	0.35	0.085	0.053	0.184	0.517	0	0.351	0.085	0.053	0.184	0.518	0
Married	-0.184	0.092	-0.029	-0.364	-0.004	0.046	-0.186	0.092	-0.03	-0.366	-0.006	0.043
Area Deprivation Index (Kind 2014)	0.003	0.002	0.029	0	0.007	0.036	0.003	0.002	0.029	0	0.007	0.034
Parental Education	-0.078	0.017	-0.068	-0.111	-0.045	0	-0.078	0.017	-0.068	-0.111	-0.045	0
Financial Difficulty	0.988	0.251	0.054	0.497	1.479	0	0.995	0.251	0.054	0.504	1.487	0
Right Amygdala Volume/1000	-0.54	0.174	-0.042	-0.882	-0.198	0.002	-0.625	0.194	-0.049	-1.006	-0.244	0.001
Right Amygdala Volume/1000 x Race (AA)							0.401	0.401	0.089	-0.385	1.187	0.317

tobacco use, while high SES White children were protected against tobacco use [56]. In the Monitoring the Future (MTF) data, high-SES White children earned the highest grade point average (GPA), while for African American children, GPA remained low in high SES people [59]. Finally, high-SES White children were protected against aggression, obesity, tobacco use, and chronic disease in the PATH data. However, African American children remained at risk of these conditions across all SES levels [54].

The MDRs are not specific only to African Americans. Diminished returns of SES indicators and other resources and assets [106] are seen for Latino [54], Asian American [128], Native American [129] LGBT [130,131], immigrant [132,133], and even marginalized White [114] people. Thus, MDRs findings are due to the mechanisms that occur in marginalization and racism [114]. Based on this model, any marginalized social identities would be associated with diminished effects of resources and assets for marginalized people. Any social status deviation from "US-born non-Latino heterosexual Whiteness" comes with a detrimental penalty in the US, which can be documented as lower returns of resources and assets at the individual and population based levels.

The observed MDRs can be attributed to unequal access to opportunity structure, different neighborhood effects, and daily experiences that collectively in the US are associated with racism and social structural diminished opportunities. The MDRs framework argues that due to structural racism, social stratification, and contextual inequalities, individual-level resources and assets show diminished returns for African American and other marginalized populations compared to Whites [105,134]. Individual-level and even family-level resources and assets, either SES or brain structure, show smaller effects for African American children than White children, because a wide range of contextual and higher-level barriers are in play and continually hinder African American communities. Discrimination is a daily chronic stressors experienced by African Americans across their life span from cradle to grave [135-138]. Compared to White families, African American families pay far more psychological and physiological taxes as costs in their upward social mobility [90]. Across all levels of resources and assets, African Americans, as a group, experience high levels of stress and discrimination [46,115], and live in high-risk schools, neighborhoods [44], and workplaces [43]. Across all SES levels, African American children are more likely to spend time with high-risk peers [43] and relatives [42]. In such context, variation in individual-level resources and assets may lose some of their behavioral or health effects [106,134]. African Americans, as a group, experience adversity, which show some risk outcomes, regardless of their individual-level

Table 3: Association between amygdala volume and negative urgency.

	Model 1						Model 2					
	b	SE	Beta	95%CI		p	b	SE	Beta	95%CI		P
Right												
Race (AA)	0.164	0.092	0.027	-0.017	0.344	0.076	-1.731	0.579	-0.281	-2.866	-0.597	0.003
Ethnicity (Hispanic)	-0.32	0.095	-0.045	-0.506	-0.133	0.001	-0.328	0.095	-0.046	-0.515	-0.142	0.001
Age (Yr)	-0.077	0.067	-0.015	-0.207	0.054	0.252	-0.074	0.067	-0.014	-0.205	0.057	0.268
Male	0.601	0.072	0.113	0.46	0.742	<0.001	0.6	0.072	0.113	0.459	0.741	<0.001
Puberty	0.466	0.077	0.078	0.316	0.617	<0.001	0.469	0.077	0.079	0.318	0.62	<0.001
Married	-0.028	0.083	-0.005	-0.191	0.135	0.735	-0.033	0.083	-0.006	-0.196	0.129	0.687
Area Deprivation Index (Kind 2014)	-0.002	0.001	-0.018	-0.005	0.001	0.188	-0.002	0.001	-0.017	-0.005	0.001	0.202
Parental Education	-0.049	0.015	-0.048	-0.079	-0.019	0.001	-0.049	0.015	-0.047	-0.079	-0.019	0.001
Financial Difficulty	0.595	0.227	0.036	0.151	1.039	0.009	0.605	0.226	0.037	0.161	1.049	0.008
Right Amygdala Volume/1000	-0.321	0.16	-0.028	-0.635	-0.007	0.045	-0.587	0.179	-0.05	-0.939	-0.236	0.001
Right Amygdala Volume/1000 x Race (AA)							1.204	0.363	0.307	0.493	1.916	0.001
Left												
Race (AA)	0.159	0.092	0.026	-0.023	0.34	0.086	-1.042	0.56	-0.169	-2.14	0.056	0.063
Ethnicity (Hispanic)	-0.324	0.095	-0.045	-0.511	-0.137	0.001	-0.333	0.095	-0.047	-0.52	-0.146	<0.001
Age (Yr)	-0.073	0.067	-0.014	-0.204	0.058	0.274	-0.074	0.067	-0.014	-0.205	0.057	0.271
Male	0.599	0.072	0.112	0.459	0.74	<0.001	0.599	0.072	0.112	0.458	0.74	<0.001
Puberty	0.467	0.077	0.079	0.316	0.618	<0.001	0.468	0.077	0.079	0.318	0.619	<0.001
Married	-0.028	0.083	-0.005	-0.191	0.135	0.737	-0.032	0.083	-0.006	-0.195	0.131	0.699
Area Deprivation Index (Kind 2014)	-0.002	0.001	-0.018	-0.005	0.001	0.179	-0.002	0.001	-0.018	-0.005	0.001	0.192
Parental Education	-0.05	0.015	-0.048	-0.079	-0.02	0.001	-0.049	0.015	-0.048	-0.079	-0.019	0.001
Financial Difficulty	0.593	0.227	0.036	0.149	1.037	0.009	0.608	0.227	0.037	0.163	1.052	0.007
Right Amygdala Volume/1000	-0.316	0.158	-0.028	-0.625	-0.007	0.045	-0.484	0.176	-0.042	-0.829	-0.14	0.006
Right Amygdala Volume/1000 x Race (AA)							0.788	0.363	0.194	0.077	1.498	0.03

resource, asset, resilience, or risk profile.

A few limitations can be discussed in this study. First, this study only investigated the correlation of amygdala volume, not other characteristics of the amygdala, such as resting-state function, task-based function, diffusivity, and functional connectivity. This study also only investigated the right and left amygdala, without studying other brain structures such as the thalamus, cerebral cortex, hippocampus, putamen, and nucleus accumbens.

Any results on the terms diminished, race, and brain development are prone to misinterpretation. As such, we need to make our position clear. We distance ourselves from any deterministic view to race and brain development. We do not suggest that one race is superior to the other race. We study brain structures and functions to document the mechanism of a negative frequent experience of racism in reducing the functional capacities of African Americans in their behavioral and physical health outcomes. This is an established observation outside the neuroscience field, and we are hoping to replicate the findings outside the neuroscience within this field. As such, similar to other domains such as mortality, chronic disease, and economic outcomes, the observed differences are shaped by social forces that hinder African American communities regardless of their variation in individual-level determinants. Studying mechanisms of social inequalities at the brain level is a step forward. However, we acknowledge that some readers may mistakenly interpret our results as biological determinism. We distance ourselves from such biological views and deterministic genetic effect on IQ and cognition. Our findings in the area of brain should be interpreted and seen in conjunction with the MDRs for Latino [54], Asian American [128], Native American [129] LGBT [130,131], immigrant [132,133], and even marginalized White [114] that share one element: marginalization. No difference, that systematic at the population level, can be due to genes. Similarly, these findings are not due to culture or behavior of African Americans at an individual level. Attributing these findings to cultural differences unfortunately is concluded when we do not consider racism and similar historic forces that reduce opportunity at the population level.

This study went beyond describing MDRs of parental and family SES on youth and children outcomes. The next step is quantifying the existing MDRs and societal causes of the observed MDRs. Research may explore how social context limits the behavioral correlation of brain structures and which social or public policies can equalize the returns of resources across racial groups. More research is needed on the mechanisms by which residential and school segregation, stratification, and discrimination contribute to African American children being high risk at all levels of risk factors. There is also a need to study structural, social, and environmental processes that cause these MDRs in African American communities. In addition, we need to investigate economic, public, education, and social policies that help reduce the existing risk for children in African American families and their children.

Limitations

Despite contributing to the literature, there were a few methodological issues which were difficult to address. Thus; our interpretation of the findings should be with caution. First, the amygdala has been linked to emotional responses much more than to emotional regulation. Mechanistically, it makes more sense based on what we know while higher cortical areas (vMPFC, DLPFC) and hippocampus are much more "tightly" linked to regulation. Second, amygdala volume studies are all correlative and assuming directionality here has no grounds. This is a profound issue with this paper. For example, Amygdala volume could be the outcome of inhibitory inputs from cortical regions similarly to behavior etc. Finally, the difference in sample sizes between Black and White participants was a problem. This could affect the significance and the strength of findings and could explain all the differences in association (not causation) between Amygdala volume and SES.

Implications

Under racism, segregation, and stratification, the effects of brain structures such as the amygdala are weaker for African American than White children. This observation is in line with the MDRs in the SES effects. While large amygdala volume reduces impulsivity, this effect is weaker for African American children than for White children. Unequal effects of equal resources are a novel mechanism that may explain some inequalities by race and ethnicity. MDRs in African American communities reflect deep structural inequalities that not only shape access to resources and assets, but also limit how much they can generate outcomes for each group. As such, at the same level of resources, African American children do worse than White children. As a result, eliminating the racial gap is necessary but not enough to promote racial equity.

Conclusion

While larger amygdala size is associated with lower impulsivity for US children, this effect is weaker for African American children than for White children. We see MDRs for the effects of SES on the amygdala [34] and MDRs for the effects of the amygdala size on impulsivity. We argue that MDRs are relevant to the effects of environmental and social inputs on the brain as well as the effects of the brain on behavior. Our approach to eliminating health inequalities requires efforts beyond equalizing SES and resources. Due to existing racism and segregation, the links between SES resources, age, brain structures, and outcomes are weaker for African American children than for White children. A true solution to health inequalities should include strategies to reduce racism, stratification, and segregation in the US.

Declaration

Conflicts of Interest: The funders had no role in the design of the study, in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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