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Original Paper

Socioeconomic Status Inequalities Partially Mediate Racial and Ethnic Differences in Children's Amygdala Volume

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Abstract

Background: *While race/ethnicity and socioeconomic status (SES) impact brain structures such as the amygdala, less is known on whether or not family SES partially explains why amygdala volume is smaller for racial and ethnic minority groups.* ***Purpose:*** *This study tested the mediating effects of family SES on racial and ethnic differences in right and left amygdala volume.* ***Methods:*** *We borrowed the structural Magnetic Resonance Imaging (sMRI) data of the Children Brain Cognitive Development (ABCD) study, a brain imaging investigation of childhood brain development in the US. The total sample was 8977, 9-10-year-old children. The independent variables were race and ethnicity. The primary outcomes were right and left amygdala volume. Age, sex, household size, and marital status were the covariates. Multiple SES indicators such as family income, subjective family SES, parental employment, parental education, and neighborhood income were the mediators. To analyze the data, we used regression models without and with our mediators. Sobel test was used to test if these mediational paths are statistically significant.* ***Results:*** *Black and Latino children had smaller amygdala sizes than non-Latino White children. The effects of race and ethnicity on amygdala volume were partially mediated by SES indicators, suggesting that one of the many reasons Black and Latino children have smaller volumes of right and left amygdala is their lower SES.* ***Conclusions:*** *For American children, lower family and neighborhood SES indicators partially, but not fully, explain smaller amygdala sizes of Black and Latino children compared to non- Latino White children.*

Keywords

amygdala, limbic system, socioeconomic position, socioeconomic status, brain development

1. Background

Racial minority status (Berger & Sarnyai, 2015; Betancourt et al., 2016; Harnett, 2020; Harnett et al., 2019) and low socioeconomic status (SES) (Hair, Hanson, Wolfe, & Pollak, 2015; Jha et al., 2019; Lawson, Duda, Avants, Wu, & Farah, 2013; Marshall et al., 2020; McLachlan et al., 2020; Oshri et al., 2019; Piccolo et al., 2016) are associated with low childhood brain development. Race and low SES correlate with experiences of stressors across domains (Javanbakht et al., 2015; Masten, Telzer, & Eisenberger, 2011; Wu et al., 2015). As a result, racial and ethnic minority and low SES children are at an increased risk of dropping out of school (Sirin, 2005), depression (Mendelson, Kubzansky, Datta, & Buka, 2008), suicide (Eisenberg, Gollust, Golberstein, & Hefner, 2007; Yildiz, Demirhan, & Gurbuz, 2019), antisocial behaviors (Palma-Coca et al., 2011), aggression (Heshmat et al., 2016), and use of tobacco (Barreto, de Figueiredo, & Giatti, 2013; Kaleta, Usidame, Dziankowska-Zaborszczyk, & Makowiec-Dabrowska, 2015), alcohol (Moore & Littlecott, 2015; Silveira et al., 2014), and drugs (Gerra et al., 2020).

Both racial and ethnic minority status and low SES correlate with brain function and structures within (Oshri et al., 2019) and across (Javanbakht et al., 2015) regions. One of the brain regions and structures that correlates with race/ethnicity and low SES is the amygdala (Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015). Racial and /ethnicity group membership and low SES are linked to the amygdala (Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015). Given the central role of amygdala reactivity in regulating emotions, behaviors, and social relations, there is a particular interest in understanding the additive effects of racial and ethnic group membership and low SES on the amygdala and associated psychopathology and behavioral problems (Dotterer, Hyde, Swartz, Hariri, & Williamson, 2017; Gard, Waller, et al., 2018; Morawetz, Bode, Baudewig, & Heekeren, 2017; Szczepanik et al., 2016; Venta et al., 2018).

While the effects of race and low SES on children’s brain function and structure go beyond just the amygdala (Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015; Kimberly et al., 2015), amygdala size and function may be among the main mechanisms by which race/ethnicity and low SES influence children emotions and behaviors (Assari, Boyce, & Bazargan, 2020; Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015). Brain imaging studies of children who are Black or have lived in poverty have shown smaller and hyperactive amygdala (Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015). The amygdala of Black and individuals who are poor show an increased activation toward negative stimuli (e.g., negative facial expressions) (Evans et al., 2016; Javanbakht et al., 2016; Javanbakht et al., 2015). Thus altered amygdala function and structure may be why race and SES are associated with high-risk behaviors (Dotterer et al., 2017; Gilliam et al., 2015; Gottlich, Kramer, Kordon, Hohagen, & Zurowski, 2015; Moadab, Bliss-Moreau, Bauman, & Amaral, 2017), poor emotion regulation (Di, Huang, & Biswal, 2017; Firk, Dahmen, Lehmann, Herpertz-Dahlmann, & Konrad, 2018; Fowler, Miernicki, Rudolph, & Telzer, 2017; Hare, Tottenham, Davidson, Glover, & Casey, 2005), and suboptimal social relations (Clark, Miller, & Hegde, 2018; Dotterer et al., 2017; Gard, Shaw, Forbes, & Hyde, 2018; Izuma, Aoki, Shibata, & Nakahara, 2019).

From a theoretical perspective, the scarcity hypothesis can explain why low SES and racial and ethnic minority status deteriorate children's brain development. According to this hypothesis, racial minorities' low SES is a proxy of early adversity and a lack of resources that all operate as risk factors for low childhood development. In this view, stress and adversity and low access to resources are the underlying mechanisms that explain the SES – brain development link (Yaple & Yu, 2019). Low family SES is a proxy of living in stressful environments, food insecurity, environmental toxins, and parental risk behaviors that can jeopardize healthy brain development in children (Assari & Mohsen Bazargan, 2019; Assari & M. Bazargan, 2019; Assari, 2019). As a result of unhealthy brain development, children with low SES backgrounds are at a higher risk of various types of psychopathologies (Chassin, Presson, Sherman, & Edwards, 1992; Kocaoglu et al., 2005; Padilla-Moledo, Ruiz, & Castro-Pinero, 2016). Low SES is also a mediator (an underlying mechanism) of racial and ethnic disparities that evolve throughout a child's development (Assari, 2018a; Assari, 2018; Assari, 2018b).

Research has established race/ethnicity and SES differences in the development of various brain regions and structures (D'Angiulli, Lipina, & Olesinska, 2012; Javanbakht et al., 2016; Javanbakht et al., 2015; P. Kim et al., 2013; Silverman, Muennig, Liu, Rosen, & Goldstein, 2009). Family SES indicators, measured as poverty, income, and parental education, impact brain function and structure (D'Angiulli et al., 2012; Javanbakht et al., 2016; Javanbakht et al., 2015; P. Kim et al., 2013; Silverman et al., 2009). In a study, individuals with low family income, at age nine, had reduced dorsolateral, ventrolateral, and prefrontal cortex activity. They also showed weaker amygdala activation suppression during effortful emotion regulation at age 24 (P. Kim et al., 2013). Javanbakht et al. (2015) showed that low family SES was associated with a higher amygdala and medial prefrontal cortical response to threatening faces, effects that were independent of adulthood SES. Another study showed a link between family SES during childhood and reduced the amygdala's connectivity with the hippocampus, posterior cingulate, superior frontal cortex, putamen, and lingual gyrus (Barch et al., 2016).

However, there is a need to advance the current literature on the additive effects of race/ethnicity and family SES on the right and left amygdala size. Our study tested the mediating effect of family SES on the association between race/ethnicity and the amygdala volume to extend the existing knowledge on social and economic mechanisms that link race/ethnicity to children's brain structure.

2. Methods

We conducted a secondary analysis of the ABCD study data (Alcohol Research: Current Reviews Editorial, 2018; Casey et al., 2018; Karcher, O'Brien, Kandala, & Barch, 2019; Lisdahl et al., 2018; Luciana et al., 2018). With a cross-sectional design, we applied data from wave 1 of the ABCD study. The ABCD is the most extensive brain imaging study of childhood brain development in the US (Alcohol Research: Current Reviews Editorial, 2018; Auchter et al., 2018). The advantages of the ABCD study include **a** national sample, a large sample size, a large sample of Blacks and Latinos, available data, robust brain development measures, and considerable socioeconomic factors (Alcohol Research: Current Reviews Editorial, 2018; Casey et al., 2018; Karcher et al., 2019; Lisdahl et al., 2018; Luciana et al., 2018). The ABCD sample was primarily recruited through the school systems with sampling informed by race, ethnicity, sex, SES, and urbanicity. More details of ABCD sampling are published elsewhere (Garavan et al., 2018). Recruitment was performed across multiple cities across states. This study measured demographic factors, family SES indicators, and amygdala volume. Structural MRI measures captured amygdala volume. A detailed explanation of the procedures and harmonization of the structural MRI in the ABCD study is available here (Casey et al., 2018). This analysis included 8977 non-twin children between the ages of 9 and 10 who had complete data on all our study variables; however, they could be of any race or ethnicity.

2.1 Primary Outcome

The primary outcome was right and left amygdala volume, measured by structural MRI. Amygdala volume is shown to be under the influence of exposure to poverty, trauma, and adversity (Calem, Bromis, McGuire, Morgan, & Kempton, 2017; Evans et al., 2016; Merz, Tottenham, & Noble, 2018).

2.2 Independent Variable

Race. Race, a self-identified variable, was coded as White (reference), Black, or other races (Asian, Mixed Race, and any non-European non-African group).

Ethnicity. Parents were asked if they are of Latino ethnic background. This variable was coded as Latino = 1 and non-Latino = 0.

2.3 Mediators

Parental Education. Parents reported their years of schooling. This variable was an interval variable ranging from 1 to 21.

Family income. Family income was an interval variable which reflected their total combined family income in the past 12 months. Coding was as below: 1.00 = less than $5000; 2.00 = $5000; 3.00 = $12,000; 4.00 = $16,000; 5.00 = $25,000; 6.00 = $35,000; 7.00 = $50,000; 8.00 = $75,000; 9.00 = $100,000; 10.00 = $200,000.

Subjective Family SES. Family SES in this study was financial difficulties measured by the following seven items: “In the past 12 months, has there been a time when you and your immediate family experienced any of the following:” 1) “Needed food but could not afford to buy it or could not afford to go out to get it?”, 2) “Were without telephone service because you could not afford it?” 3) “Did not pay the full amount of the rent or mortgage because you could not afford it?”, 4) “Were evicted from your home for not paying the rent or mortgage?”, 5) “Had services turned off by the gas or electric company, or the oil company would not deliver oil because payments were not made?”, 6) “Had someone who needed to see a doctor or go to the hospital but did not go because you could not afford it?” and 7) “Had someone who needed a dentist but could not go because you could not afford it?” Responses to each item were either 1 or 0. We calculated a sum score with a potential range between 0 and 7—a higher score indicating lower family SES. Our variable was a continuous measure. Financial difficulties are an accepted SES indicator (Assari, Preiser, Lankarani, & Caldwell, 2018; Assari, Smith, Mistry, Farokhnia, & Bazargan, 2019; Boe, Petrie, Sivertsen, & Hysing, 2019; Chen & Paterson, 2006; Moon, 1987; Wright & Steptoe, 2005; Ye, Wen, Wang, & Lin, 2020).

Neighborhood Income. The median family income of the neighborhood was derived from ABCD residential history. This is in line with the Area Deprivation Index (ADI), based on the Health Resources & Services Administration (HRSA) work, Kind, Diez Roux, and others. Neighborhood income reflected county-level / census block group/neighborhood. Extensive research suggests that ADI, median family income, and neighborhood income predict health (Duran, Diez Roux, Latorre Mdo, & Jaime, 2013; D. Kim, Diez Roux, Kiefe, Kawachi, & Liu, 2010; Linetzky, Mejia, Ferrante, De Maio, & Diez Roux, 2012; Nordstrom, Diez Roux, Jackson, Gardin, & Cardiovascular Health, 2004).

2.4 Confounders

Age. Age was a dichotomous variable 9 or 10. Parents reported the age of the children.

Sex. Sex was coded as 1 for males and 0 for females.

Parental Marital Status. Parental marital status was 1 for married and 0 for any other condition (reference).

Parent's Employment. A dichotomous variable recorded the employment status of the parent. The variable was coded as 0 for no employed parent in the household (reference), and 1 for at least one parent employed. This variable was self-reported by the parent who was interviewed.

2.5 Data Analysis

*W*e used SPSS 22.00 for data analysis. Frequencies (n and %) and mean [standard deviations (SDs)] were described. To estimate bivariate analyses between the study variables, we used the Pearson correlation in the pooled sample. Then we performed two regression models. *Model 1* did not have the mediators. *Model 2* was performed with the mediators—all these models controlled for all confounders. Family SES indicators were the mediators. Both models were performed in the pooled sample. The independent variables were race and ethnicity. Outcomes were right and left amygdala volume. Unstandardized regression coefficient (b), SE, and p-values were reported for each model. A p-value of equal or less than 0.05 was significant. We did not include marital status as an SES indicator, which is an accepted practice (Denney, Rogers, Krueger, & Wadsworth, 2009). To test if the indirect effects of race and ethnicity on the right and left amygdala are via SES, we used the Sobel test to test if SES operates as a mediator variable and significantly carries the influences of race and ethnicity (independent variables) on the right and left amygdala volume (dependent variables). Sobel test is an accepted test of indirect effect and mediation(Preacher & Leonardelli, 2001).

2.6 Ethical Aspect

Our analysis was exempt from a full review. However, the ABCD study protocol was approved by the University of California, San Diego ethics committee (Auchter et al., 2018).

3. Results

3.1 Descriptives

The sample included 8977 9-10 years old children. Table 1 describes the sample. The right amygdala volume was larger for White (1638.02 ±230.00) than for Black (1536.78 ±220.22) children ($p < 0.001$). Left amygdala volume was also larger for White (1601.05 ±232.77) than for Black (1482.71 ±213.29) children ($p < 0.001$).

Table 1. Descriptive Data (*n* = 8977)

	n	**%**
Race		
Other	7201	80.2
Black	1776	19.8
Race		
White or Black	8210	91.5
Other	767	8.5
Ethnicity		
Non-Latino	7194	80.1
Latino	1783	19.9
Sex		
Male	4263	47.5
Female	4714	52.5
Age		
9 Years	4829	53.8
10 Years	4148	46.2
Family Marital Status		
Not- Married	2809	31.3
Married	6168	68.7
Parental Employment		
No	2688	29.9
Yes	6289	70.1
	Mean	**SD**
Parental Education (1-21)	16.74	2.68
Subjective Family Socioeconomic Status (0-1)	0.93	0.16
Family Income (1-10)	7.17	2.43
Neighborhood Income	76.70	35.52
Right Amygdala Size (mm3)	1604.42	228.26
Left Amygdala Size (mm3)	1560.00	231.30

3.2 Unadjusted Bivariate Correlations

Table 2 shows the unadjusted bivariate correlations using the Pearson test. Family and neighborhood SES indicators were positively correlated with amygdala volume.

Table 2. Bivariate Associations (*n* = 8977)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Race (Other)	1.00	-.15**	.29**	-.01	.01	-.05**	-.04**	-.11**	-.02	-.11**	-.07**	-.04**	-.06**
2 Race (Black)		1.00	-.13**	-.01	.01	-.37**	-.02*	-.25**	-.25**	-.36**	-.36**	-.15**	-.16**
3 Ethnicity (Latino)			1.00	.00	-.02	-.11**	-.05**	-.25**	-.09**	-.25**	-.24**	-.05**	-.06**
4 Sex (Male)				1.00	.01	.02	-.01	-.02	-.01	.01	.01	.32**	.32**
5 Age (Year)					1.00	-.00	.02*	.00	.03*	.02*	.03**	.04**	.06**
6 Marital Status (Married)						1.00	.02	.34**	.30**	.53**	.35**	.11**	.11**
7 Parents Employed							1.00	.23**	.13**	.23**	.12**	.04**	.04**
8 Parental Education (1-21)								1.00	.34**	.62**	.49**	.12**	.11**
9 Subjective Family Socioeconomic Status (0-1)									1.00	.46**	.32**	.08**	.09**
10 Family Income (1-10)										1.00	.61**	.14**	.14**
11 Neighborhood Income											1.00	.11**	.13**
12 Right Amygdala Volume (mm3)												1.00	.73**
13 Left Amygdala Volume (mm3)													1.00

*p < 0.05 ** p < 0.01

Table 3 reports the results of two pooled sample regression models with the right amygdala volume as the outcome. *Model 1*, which only included race and ethnicity with confounders (age, sex, and marital status), showed that race and ethnicity are associated with right amygdala volume. *Model 2* showed that family and neighborhood SES indicators partially mediate race and ethnicity’s effects on the right amygdala volume.

Table 3. Regressions Models for Right Amygdala Volume (*n* = 8977)

	Beta	b	SE	95% CI		t	p
Model 1							
Race (Other)	-0.04	-36.59	8.48	-53.21	-19.96	-4.31	< .001
Race (Black)	-0.14	-79.06	6.24	-91.29	-66.84	-12.68	< .001
Ethnicity (Latino)	-0.05	-26.94	5.98	-38.66	-15.21	-4.50	< .001
Sex (Male)	0.32	144.40	4.50	135.58	153.22	32.10	< .001
Age (Year)	0.04	18.16	4.51	9.33	27.00	4.03	< .001
Marital Status (Married)	0.04	22.13	5.31	11.72	32.53	4.17	< .001

Model 2							
Race (Other)	-0.04	-28.89	8.51	-45.58	-12.21	-3.39	.001
Race (Black)	-0.12	-67.85	6.62	-80.83	-54.88	-10.25	< .001
Ethnicity (Latino)	-0.03	-15.39	6.28	-27.70	-3.09	-2.45	.014
Sex (Male)	0.32	145.19	4.48	136.40	153.98	32.37	< .001
Age (Year)	0.04	17.64	4.50	8.83	26.45	3.92	< .001
Marital Status (Married)	0.01	5.20	5.97	-6.50	16.90	0.87	.384
Parents Employed	0.01	5.40	5.18	-4.74	15.55	1.04	.297
Parental Education (1-21)	0.05	4.56	1.11	2.38	6.74	4.11	< .001
Subjective Family Socioeconomic Status (0-1)	0.01	16.50	15.73	-14.33	47.33	1.05	.294
Family Income (1-10)	0.06	5.40	1.50	2.47	8.34	3.61	< .001
Neighborhood Income	-0.03	-0.17	0.08	-0.32	-0.02	-2.19	.028

Outcome: right amygdala volume

Table 4 reports the results of two pooled sample regression models with left amygdala volume as the outcome. *Model 1*, which only included race and ethnicity with confounders (age, sex, and marital status), showed that race and ethnicity are associated with left amygdala volume. *Model 2* showed that family SES partially mediates the effects of race and ethnicity on left amygdala volume.

Table 4. Regression Models for Left Amygdala Volume (*n* = 8977)

	Beta	b	SE	95% CI		T	p
Model 1							
Race (Other)	-0.06	-45.83	8.56	-62.62	-29.05	-5.35	< .001
Race (Black)	-0.15	-89.09	6.30	-101.43	-76.75	-14.15	< .001
Ethnicity (Latino)	-0.05	-31.33	6.04	-43.17	-19.50	-5.19	< .001
Sex (Male)	0.31	144.95	4.54	136.04	153.85	31.91	< .001
Age (Year)	0.06	26.95	4.55	18.03	35.87	5.92	< .001
Marital Status (Married)	0.04	22.01	5.36	11.50	32.51	4.11	< .001
Model 2							
Race (Other)	-0.05	-40.38	8.61	-57.25	-23.51	-4.69	< .001
Race (Black)	-0.13	-77.47	6.69	-90.58	-64.35	-11.58	< .001
Ethnicity (Latino)	-0.04	-21.02	6.35	-33.45	-8.58	-3.31	.001
Sex (Male)	0.31	145.70	4.53	136.81	154.59	32.14	< .001
Age (Year)	0.06	26.13	4.54	17.22	35.04	5.75	< .001
Marital Status (Married)	0.02	7.96	6.03	-3.87	19.79	1.32	.187
Parents Employed	0.02	8.46	5.23	-1.79	18.72	1.62	.106
Parental Education (1-21)	0.03	2.98	1.12	0.78	5.17	2.65	.008
Subjective Family Socioeconomic Status (0-1)	0.02	34.19	15.90	3.03	65.35	2.15	.032

Family Income (1-10)	0.04	3.55	1.51	0.59	6.52	2.35	.019
Neighborhood Income	0.00	-0.02	0.08	-0.17	0.14	-0.20	.842

Outcome: left amygdala volume

3.3 Sobel Test of Mediation

Our Sobel tests suggested that SES indicators operate as partial mediator variables, meaning that they significantly carry some of the influences of race and ethnicity (independent variables) on the right and left amygdala volume (dependent variables). As such, some of the effects of race and ethnicity on amygdala volume are indirect and through SES (mediator variable).

4. Discussion

Two findings were observed. First, race/ethnicity and family SES are associated with the right and left amygdala volume. Second, the smaller amygdala size of Black and Latino children than non- Latino White children is, in part, explains the observed racial and ethnic gaps in amygdala size. However, SES partially, not fully, mediates the racial and ethnic differences in right and left amygdala volume.

Family SES has a profound effect on the brain (Brito & Noble, 2014; Finn et al., 2017; Gonzalez et al., 2020; K. G. Noble, 2014; K. G. Noble, Houston, Kan, & Sowell, 2012) and behavior (D'Angiulli et al., 2012; Javanbakht et al., 2016; Javanbakht et al., 2015; P. Kim et al., 2013; Silverman et al., 2009). Studies by Javanbakht and others have shown that high family SES shapes the amygdala function in response to negative stimuli. The first study included 52 predominantly White subjects from a prospective longitudinal study and established a link between high family SES (childhood poverty) and lower amygdala response levels to threatening faces. This effect was independent of adulthood income. They also showed a link between family SES (childhood poverty) and reduced functional connectivity between the left amygdala and the medial prefrontal cortex (Javanbakht et al., 2015). In another study, Javanbakht et al. documented sex differences in childhood family SES effects on amygdala activity. They found that childhood poverty status may be correlated with amygdala reactivity to fearful faces in females but not males (Javanbakht et al., 2016). In their third study lead by Evans, social adversities showed cumulative (additive) effects on amygdala structure and function (including the amygdala's response to threatening faces) (Evans et al., 2016).

Low SES and poverty are associated with a lower level of connectivity in neural networks involved in emotion regulation, especially for children who receive low levels of supportive parenting (Brody et al., 2019). Childhood poverty is linked to reduced connectivity between the amygdala and putamen, superior frontal cortex, lingual gyrus, and posterior cingulate. Childhood poverty predicts connectivity between the right lingual gyrus and the right amygdala; these brain connectivity indicators explain why early poverty predicts childhood depression (Barch et al., 2016).

Our study findings suggested that some of the racial and ethnic variations on brain structure are due to SES. We found that SES partially explains why racial and ethnic minorities have a smaller amygdala size.

Theoretically speaking, one mechanism that can explain the results is everyday exposure of Black and Latino families to discrimination (Assari, Gibbons, & Simons, 2018; Assari & Lankarani, 2017; Assari, Lankarani, & Caldwell, 2018; Assari, Miller, et al., 2018; Assari, Moghani Lankarani, & Caldwell, 2017). We, however, did not test discrimination in the data set for a few reasons. In a study, chronic discrimination was associated with altered connections between the amygdala and other brain regions such as the insula, putamen, caudate, medial frontal gyrus, and anterior cingulate (Clark et al., 2018).

It should be emphasized again that similar to SES, we see race and ethnicity as social factors (as proxies of racism, social stratification, exposure to stress, and blocked opportunities). In other terms, race and SES reflect how and individuals and groups are treated by society. We specifically focused on the amygdala, which shapes social relations and emotion processing/ regulation. The amygdala's small size (shrink amygdala) is reported in psychopathologies and chronic exposure to stress (MacMaster et al., 2008).

For our study, we included separate SES indicators rather than a summary score. Future research could create a summary SES score by running principal component analysis. Such an approach could result in a different level of the explanatory power of SES.

5. Conclusions

In summary, low family and neighborhood SES indicators partially explain why racial and ethnic minority status is correlated with smaller amygdala volume. That means some of the racial and ethnic differences observed in brain structures are shaped by economic disadvantages that racial and ethnic minorities, particularly Black and Latino families, experience.

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Conflicts of Interest: None.

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