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Associations between socioeconomic status and cortical thickness in prefrontal cortical subregions

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Abstract

Childhood socioeconomic status (SES) is highly predictive of a wide range of life outcomes, ranging from cognitive ability and academic achievement to physical and mental health. Recent work investigating more specific correlates of SES has identified SES disparities in executive function performance and measures of prefrontal cortical function, but little is known about the structural correlates of childhood socioeconomic status. Structural MRI and demographic data from a sample of 283 healthy children in the first wave of the NIH MRI Study of Normal Brain Development were used to systematically investigate the relationship between SES and frontal cortical thickness. Specifically, we assessed the association between two principal measures of childhood SES, family income and parental education, on grey matter thickness in specific subregions of prefrontal cortex and on the asymmetry of these areas. After correcting for multiple comparisons and controlling for potentially confounding variables, parental education significantly predicted cortical thickness in the right anterior cingulate gyrus and left superior frontal gyrus. These results suggest that brain structure in frontal regions may provide a meaningful link between SES and cognitive function among healthy, typically developing children.

Key words: socioeconomic status, SES, poverty, structural neuroimaging, prefrontal cortex, brain development

There is a clear link between socioeconomic status (SES) and cognitive outcomes: children who grow up in poverty tend to have lower IQs and academic achievement scores, are less likely to graduate high school, and are less likely to develop basic reading and mathematics proficiency than their higher-SES counterparts (Brooks-Gunn & Duncan, 1997; Gottfried, Gottfried, Bathurst, Guerin, & Parramore, 2003; Sirin, 2005). These outcome measures, while clinically meaningful, reflect the combined influence of many specific neurocognitive systems. It is these underlying systems that mediate the association between SES and cognitive performance and provide possible targets for interventions designed to reduce SES disparities. The methods of cognitive neuroscience, such as neuropsychological testing and structural brain imaging, may make it possible to identify specific neurocognitive systems that vary along socioeconomic gradients.

The goal of the present study is to investigate the relation between SES and prefrontal cortical thickness in healthy normal children. We focus on prefrontal cortex for three reasons. First, this brain region is essential for executive function, which is associated with academic success (Blair & Diamond, 2008; Ursache, Blair & Raver, 2011) and intelligence as measured by psychometric tests (Deary, Penke & Johnson, 2010). Second, the long developmental trajectory of prefrontal cortex (Casey, Giedd & Thomas, 2000; Gogtay et al., 2004), and its sensitivity to environmental factors including stress (McEwen & Gianaros, 2011), suggest that differences in the experiences of lower and higher SES children could impact prefrontal development. Third, and most directly relevant, many studies have found SES differences in executive function and in prefrontal activity.

In children ranging from infancy to adolescence, SES has been found to correlate with executive function as measured by many different tasks (Ardila, Rosselli, Matute & Guajardo, 2005; Lipina, Martelli, Vuelta & Colombo, 2005; Lipina, Martelli, Vuelta, Injoque-Ricle & Colombo, 2004; Mezzacappa, 2004; Sarsour et al., 2011) and as measured by latent executive function constructs derived from multiple executive function tasks (Blair et al., 2011; Hughes, Ensor, Wilson & Graham, 2010; Rhoades, Greenberg, Lanza & Blair, 2011; Wiebe et al., 2011). Furthermore, in studies where multiple neurocognitive systems have been assessed, executive function appears to be disproportionately affected by SES (Farah et al., 2006; Noble, McCandliss & Farah, 2007; Noble, Norman & Farah, 2005). Additionally, ERP studies in children have demonstrated SES differences in measures of selective attention associated with prefrontal cortex (D'Anguilli, Herdman, Stapells & Hertzman, 2008; Kishiyama, Boyce, Jimenez, Perry & Knight, 2008; Stevens, Lauinger & Neville, 2009). Other behavioral and electrophysiological evidence regarding SES differences in executive function and prefrontal activity are reviewed by Hackman and Farah (2009), who find the vast majority, but not all, of the relevant published studies show that higher SES in children is accompanied by higher executive function and/or more mature or advantageous patterns of brain activity. The ways in which SES has been operationalized in these studies have included parental education, total family income, family income-to-needs ratio and combinations of education and income measures.

Relatively few published studies report the effects of childhood SES on brain structure, and most have focused on regions other than prefrontal cortex. SES as measured by family income, but not parental education, has been found to predict hippocampal grey-matter volume in a large sample of healthy children between the ages of 4 and 18 (Hanson, Chandra, Wolfe & Pollack, 2011). A separate study of 60 children yielded a similar result, with hippocampal volume predicted by family income-to-needs ratio and not parental education (Noble, Houston, Kan & Sowell, in press). That study also found that amygdala volume was predicted by education but not by income-to-needs. Most relevant to prefrontal areas, this study also revealed an interaction between age and parental education (but not a main effect of parental education) in left perisylvian areas including the left inferior frontal gyrus. A marginally significant correlation between SES and inferior frontal gyrus gray matter volume was observed in a small sample of 5-year-old children (Raizada, Richards, Meltzoff & Kuhl, 2008).

In a large sample of typically developing children, family income and parental education were not found to significantly predict whole-brain or gross regional volumes, including frontal lobe volume (Brain Development Cooperative Group, 2012; Lange, Froimowitz, Bigler, Lainhart & Brain Development Cooperative Group, 2010). This same data set was also analyzed by Andrew Beck, whose results are reported in an unpublished undergraduate thesis (2010), relating overall prefrontal gray matter volume to SES. Beck found a weak but statistically significant (regression coefficient of .06) relation between family income and gray matter volume in this data set.

In sum, a growing literature documents robust SES differences on tasks dependent on prefrontal cortex. There is also ERP evidence consistent with SES differences in prefrontal function. However, there is surprisingly little direct evidence on the relation between SES and prefrontal cortex structure. The present study is an attempt to provide additional direct evidence on the relation between SES and prefrontal structure in children using more sensitive and specific measures of regional morphology.

The present study uses the same large data set referred to earlier (Evans, 2006; Brain Development Cooperative Group, 2012; Lange, et al, 2010). Unlike the earlier studies, which analyzed overall lobar volume, we focus our analyses on subregions of prefrontal cortex using a measure of cortical thickness rather than volume. Cortical thickness is defined, in neuroimaging studies, as the shortest distance between the white matter surface and pial gray matter surface. This quantitative measurement provides a direct index of cortical morphology that can be measured reliably using multiple approaches (Lerch & Evans, 2005). Furthermore, cortical thickness may be a more specific measure of brain morphology than gray matter volume. Grey matter volume is a function of both cortical thickness and surface area, which are genetically and phenotypically independent (Winkler et al., 2010). Cortical thickness has been shown to be a meaningful index of brain development, showing associations with age (Shaw et al., 2008; Sowell et al., 2004), cognitive ability (Porter, Collins, Muetzel, Lim & Luciana, 2011; Shaw et al., 2006) and behavior (Ducharme et al., 2012; Shaw et al., 2011).

Our analyses are designed to examine the relation between SES and regional cortical thickness in children's prefrontal cortex and to answer a series of more specific questions: Which subregions of prefontal cortex are related to childhood SES? Does SES predict assymetry of prefrontal regions? Does the relation between SES and prefrontal cortical thickness depend on the age at which the child is assessed? Finally, which more specific aspects of SES, represented by parental education and by family income, are related to prefrontal cortical thickness? Each of these questions is motivated by previous research in the cognitive neuroscience of executive function, human and animal stress physiology, longitudinal studies of brain development in humans, and psychological and sociological studies of child development, as well as specific studies on SES and the brain.

The importance of inquiring about subregions of prefrontal cortex, rather than prefrontal or frontal brain regions overall, is suggested by an extensive literature showing specialization within prefrontal cortex for different aspects of executive function. Although the delineation of executive function components and their anatomical localization remains inconclusive (e.g. see

Badre & D'Esposito, 2009; Duncan & Owen, 2000; Wilson, Gaffan, Browning & Baxter, 2010 for different views) and developing executive function may relate to brain structure in distributed regions (e.g. Tamnes et al., 2010), certain broad generalizations are possible. Working memory, for which many different tasks have revealed SES differences, is associated with lateral prefrontal regions, including the superior, middle and inferior frontal gyri (e.g. Boisgueheneuc, 2006; D'Esposito et al., 1998). Cognitive control, the ability to inhibit inappropriate responses and promote flexible, task-relevant processing, is associated with medial prefrontal areas including the anterior cingulate gyrus (e.g. Botvinick, Cohen & Carter, 2004; Kerns et al., 2004). Self-control in the face of rewards, sometimes classified as an executive function but frequently not found to differ with children's SES (e.g. Farah et al., 2006; Li-Grining, 2007; Noble, Norman & Farah, 2005, but see Evans & Rosenbaum, 2008), is generally associated with orbital prefrontal cortex (e.g. Dias, Robbins & Roberts, 1996; Rolls, 2000).

The possibility that structural correlates of SES might consist of differences in asymmetry is suggested by previous research using hemifield visual stimulus presentations (see Boles, 2011 for a review) as well as a functional MRI study finding more symmetric activation of Broca's area in a language task with children (Raizada, et al., 2008). Age is considered as a possible moderator of SES effects on prefrontal cortical thickness for two reasons. First, prefrontal cortex undergoes prolonged development with nonlinear, and even nonmonotonic, changes in cortical thickness over the range of ages studied here. These changes may reflect the processes of synaptic proliferation and pruning or the effect of myelination on the measurement of thickness (Giedd et al., 1999; Paus, 2005). To the extent that SES differences reflect either differences in the rate of development or differences in developmental processes occuring at specific ages, then SES differences in cortical thickness will not be constant over age. The second reason to check for age-by-SES interactions comes from Noble et al. (in press), who report such an interaction in the size of language areas including the left inferior frontal gyrus.

Finally, we separately assess the predictive power of parental education and family income in view of previous research showing different influences of these measures on child development (see Duncan & Magnussen, in press, for a review). Hippocampal volume (Hanson et al., 2011; Noble et al., in press) has been found to correlate with family income measures and not with parental education. One study found parental education but not income predicted SES relationships with cortex (Noble et al., in press) and one found income did so without additional predictive power by adding parental education (Beck, 2010).

Methods

Participants

Data used in the preparation of this article were obtained from the NIH Pediatric MRI Data Repository created by the NIH MRI Study of Normal Brain Development (Evans, 2006; website: https://nihpd.crbs.ucsd.edu/nihpd/info/index.html), a public-access database designed to be a research tool for investigations of healthy brain and behavior development. This is a multisite, longitudinal study of typically developing children from ages newborn through young adulthood conducted by the Brain Development Cooperative Group and supported by the National Institute of Child Health and Human Development, the National Institute on Drug Abuse, the National Institute of Mental Health, and the National Institute of Neurological Disorders and Stroke (Contract #s N01-HD02-3343, N01MH9-0002, and N01-NS-9-2314, -2315, -2316, -2317, -2319 and -2321). A listing of the participating centers and a complete listing of the study investigators can be found at: https://nihpd.crbs.ucsd.edu/nihpd/info/participating_centers.html.

As part of Objective 1 of the study, structural MRI, behavioral and clinical measures were collected at three timepoints for 433 healthy children and adolescents between the ages of 4:6 and 18:3 years. Children were excluded from participation in the study based on rigorous demographic, prenatal history, physical, behavioral, family history, and neurological criteria (see Evans, 2006 for a full description of inclusionary and exclusionary criteria). Data collection occurred at 6 pediatric study centers in major urban areas and population-based sampling was used to obtain a demographically-representative sample (Evans, 2006). All protocols were approved by the relevant Institutional Review Board at each pediatric study center. The Institutional Review Board at the University of Pennsylvania also approved the analysis of these human-subjects data.

All analyses in the current study use cross-sectional data from the first wave of data collection for Objective 1 of the study. A self-report measure of family income was obtained in 10 possible levels: 0-$5,000, $5,001-$10,000, $10,001-$15,000, $15,001-$25,000, $25,001-$35,000, $35,001-$50,000, $50,001-$75,000, $75,001-$100,000, $100,001-$150,000, and over $150,000. Parental education level was measured in six possible categories for each parent: less than high school, high school, some college, college, some graduate level, graduate level. Finally, race (White, African American/Black, Asian, American Indian/Alaskan Native, Native Hawaiian/Pacific Islander) and ethnicity (Hispanic or Latino, Not Hispanic or Latino) was reported for each parent.

Of the 431 children with Wave 1 behavioral data, 283 children had available MRI data that met quality control standards as well as available data for all covariates used in analysis.

Demographic data for the children used in analysis are summarized in Table 1. The subset of children used in analysis did not differ from the excluded children in gender ($p = .427$), IQ ($p = .071$), parental education ($p = .652$), or family income ($p = .829$). However, the MRI sample had a significantly older age ($p = 1.03*10^{-17}$) than the sample of children without MRI data or covariates.

SES indicators

Family income was estimated as the midpoint of the reported income range (as summarized in Table 1) and was adjusted for household size based on adjustments used by the US Department of Housing and Urban Development (HUD) to define the highest income level at which a family qualifies for public assistance. Each parent's education level was assigned a value from 1-6 (Less than High School = 1, High School = 2, Some College = 3, College = 4, Some Graduate Level = 5, Graduate Level = 6). Maternal education level and paternal education level were summed for each child in order to create a parental education index with possible values from 2 to 12. The parental education variable was square-root transformed in order to reduce violations of normality assumptions.

Image processing

Multi-spectral MRI data were collected on 1.5T scanners in six imaging centers in the U.S. In the current study, we processed the T1-weighted MR images. Image processing was based on the open-source program Advanced Normalization Tools (ANTS) (http://www.picsl.upenn.edu/ANTS/) and the associated pipelining framework PipeDream (sourceforge neuropipedream). ANTS was used to create a population averaged template. The template was initialized using data from 31 subjects who had 1mm isotropic T1-weighted images and were representative of the sample in terms of age, gender, scan site, and SES. In the final iteration of template building, all subjects were included. Multi-atlas labeling techniques (Heckemann, Hajnal, Aljabar, Rueckert & Hammers, 2006) implemented in the Iapetus tool included with ANTS were then used along with publicly available data sets for brain masking (Shattuck et al., 2007), three tissue segmentation (http://www.nirep.org/) and region labeling (Hammers et al., 2003) in the template. Each subject was then processed using Pipedream which uses the symmetric normalization methodology (Avants et al., 2011) to diffeomorphically normalize each subject to a template. The template segmentations were then propagated into subject space and used as priors for the Markov Random Field approach implemented in the ANTS tool Atropos, which has been validated on public datasets (Avants, Tustison, Wu, Cook & Gee, 2011). Cortical thickness was estimated using Diffeomorphic Registration Based Cortical Thickness (DiReCT) (Das, Avants, Grossman & Gee, 2009). DiReCT uses diffeomorphic mapping within a prior-constrained estimate of the distance between the gray/white interface and the gray/cerebrospinal fluid interface to estimate cortical thickness (Das et al., 2009). Each cortical region of interest was defined by multiplying the subjects' cortical segmentation by the region of interest label. The mean cortical thickness was then computed within the cortical ROI.

Regions of interest

The selection of regions of interest (ROIs) was guided by the literature reviewed earlier on neurocognitive SES disparities, as well as the literature on the effects of stress on brain development. Regions associated with executive functions found to differ as a function of childhood SES included left and right superior frontal gyri, left and right middle frontal gyri, left and right inferior frontal gyri, and left and right anterior cingulate gyri. Regions susceptible to stress also include the left and right anterior cingulate gyri and left and right orbitofrontal gyri.

In addition, three asymmetry measures were calculated as follows and treated as a priori measures of interest: left-minus-right superior frontal gyrus, left-minus-right middle frontal gyrus, left-minus-right inferior frontal gyrus.

Statistical approach

Analysis used hierarchical linear regression executed in Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL) to predict cortical thickness in each region of interest from parental education and family income. Using an approach similar to Noble et al. (in press), parental education and family income were added together in the last step of a hierarchical linear regression model.

In the first step, ROI thickness was predicted from age (in days), gender, total brain volume, Full-Scale IQ (Wechsler, 1999), body mass index (BMI), and child/race ethnicity (dummy-coded as 'White' or 'Non-White'). While it has been argued that it is often unjustified to control for IQ in studies of neurocognitive outcomes (Dennis et al., 2009), previous studies with this dataset report associations between cortical thickness and IQ (Karama et al., 2009; Karama et al., 2011), suggesting that IQ should be considered a possible confounding variable. Body mass index, calculated as (Weight in kg)/(height in m)^2, was used as a covariate because it has been shown to significant predict structural measures, including whole-brain gray-matter and white-matter volume in the visit 1 NIHPD data (Brain Development Cooperative Group, 2012). The BMI variable was winsorized due to an extreme outlier. Child race/ethnicity was coded based on reported parental race/ethnicity, and only two categories were used in order to prevent the creation of categories with small numbers of children. Scan site was not used as a covariate because socioeconomic variables were not evenly distributed across testing sites.

In the next, critical, step, parental education and family income were added to the model. Change in model R squared and F statistics are reported along with regression coefficients. Bonferroni correction was used to correct for multiple comparisons of 13 regions of interest by setting alpha at .0038 (e.g. .05/13), and results are reported using both uncorrected ($p < .05$x) and corrected ($p < .0038$) alpha levels.

Results

The parental education and family income variables were significantly correlated with each other ($r = .573$, $p = 4.70 * 10^{-26}$) and with full scale IQ (parental education $r = .406$, $p = 1.11 * 10^{-12}$; family income $r = .347$, $p = 2.08 * 10^{-9}$). Neither SES variable was significantly correlated with gender, age, BMI, or total brain volume (all p values > .07).

Using the uncorrected threshold of $p < .05$, a significant change in the model F statistic was found after adding parental education and family income to the model in the left anterior cingulate gyrus (R^2 change = .022, F change = 3.198; p = .042), right anterior cingulate gyrus (R^2 change = .054, F change = 8.098; $p = 3.83 * 10^{-4}$) left superior frontal gyrus (R^2 change = .036, F change = 6.094; $p = 2.57 * 10^{-3}$), right superior frontal gyrus (R^2 change = .024, F change = 4.085; p = .018), and superior frontal asymmetry measure (R^2 change = .036, F change = 5.253; $p = 5.77 * 10^{-3}$). Change in model R^2 and regression coefficients for the SES variables for all ROIs are displayed in Table 2.

Only the right anterior cingulate gyrus (mean thickness: 2.371 mm; standard deviation .321) and left superior frontal gyrus (mean thickness 2.659 mm, standard deviation .312) met the corrected threshold of $p < .0038$. Results of the hierarchical regression for the right anterior cingulate gyrus and left superior frontal gyrus are shown in Table 3. In both cases, parental education significantly predicted the ROI while family income did not when the two SES variables were in the model simultaneously. Scatterplots of ROI thickness and parental education for the right anterior cingulate gyrus and left superior frontal gyrus are shown in Figures 1 and 2.

To further investigate the differential ability of family income and parental education to predict cortical thickness in these ROIs, the model was repeated for the right anterior cingulate gyrus and left superior frontal gyrus using family income and parental education as independent predictors. In the right anterior cingulate gyrus, when controlling for age, gender, total brain volume, race, BMI and IQ, parental education alone significantly predicted greater thickness ($\beta = .250$, $p = 1.27 * 10^{-4}$), while family income alone did not predict thickness ($p = .320$). Using the same model to predict thickness in the left superior frontal gyrus, parental education alone significantly predicted greater thickness ($\beta = .193$, $p = 1.51 * 10^{-3}$), while family income alone did not predict thickness ($p = .692$).

When a parental education x age interaction was added to the model, model fit improved only in the left orbitofrontal gyrus (R^2 change = .018, F change = 5.456, $\beta = -.960$; $p = .020$) and right orbitofrontal gyrus (R^2 change = .020, F change = 6.067, $\beta = -1.022$; $p = .014$). These effects were significant at the uncorrected alpha level of .05, but did not survive bonferroni correction.

Discussion

Within this large sample of healthy children, parental education predicted increased cortical thickness in the left superior frontal gyrus and right anterior cingulate gyrus, using a conservative threshold for statistical significance. The association between SES and thickness in the right anterior cingulate gyrus is interesting in light of a previous publication from this dataset reporting an association between relatively thin right anterior cingulate cortex and higher scores on the Aggressive Behavior scale of the Child Behavior Checklist (Ducharme et al., 2011). A measure of superior frontal asymmetry also showed SES differences, although they did not survive stringent correction for multiple comparisons. While SES differences in behavioral measures of executive function and ERP measures of prefrontal cortical function have previously been documented, this study provides novel structural evidence for SES differences in selective regions of the prefrontal cortex. These findings add to the emerging literature suggesting that SES relates to structural brain variation, with other studies of healthy children reporting main effects of SES in the hippocampus (Hanson et al., 2011; Noble et al., in press) and amygdala (Noble et al., in press). However, unlike previous studies, the current analysis did not show an SES main effect or age interaction in the left inferior frontal gyrus, which may reflect differences between cortical thickness and volumetric measures.

One interesting and unexpected finding was the fact that parental education and family income, while highly correlated, showed strong differences in their ability to predict cortical thickness in frontal regions of interest. Parental education, but not family income, significantly predicted thickness in the right anterior cingulate gyrus and left superior frontal gyrus. The strong difference between the predictive ability of parental education and family income provides support for the argument that SES indicators capture different aspects of environmental and genetic variation and should be treated separately (Bravemen et al., 2005; Duncan & Magnussen, in press) but the mechanism for differences between parental education and family income is unclear. This difference may simply reflect differences in the sensitivity of the education and income scales in this dataset, or it may reflect meaningful differences in the genetic or environmental factors associated with these SES measures.

The observational nature of this study is an important limitation, and results cannot be used to infer the direction of causality. Cortical thickness in frontal regions has been shown to be moderately heritable (Joshi et al., 2011; Winkler et al., 2010) though heritability measures of cognitive (Harden, Turkheimer & Loehlin, 2007; Turkheimer, Haley, Waldron, D'Onofrio & Gottesman, 2003) and structural brain (Chiang et al., 2011) measures have been found to be reduced in low-SES populations. Socioeconomic status is a distal measure that is associated with both genetic and environmental differences (Hackman, Farah & Meaney, 2010), but genetic or proximal environmental factors were not measured in this study, and reported associations between SES and cortical thickness likely reflect combined genetic and environmental influences. Future research on the structural correlates of SES will benefit from including measures of more proximal environmental factors (e.g. stress, cognitive stimulation) and examining the extent to which they mediate the relationship between SES and brain structure. Early work (Rao et al., 2010) demonstrating associations between specific aspects of the home environment and brain structure suggests that this may be a promising approach. Stress, which is associated both with SES (Cohen, Doyle & Baum, 2006; Evans & English, 2011; Lupien, King, Meaney & McEwen, 2001) and differences in prefrontal brain morphology (Cerquieria, Mailliet, Almeida, Jay & Sousa, 2007; Lupien, McEwen, Gunnar & Heim, 2009; McEwen & Gianaros, 2011;), may be another proximal environmental factor that provides a link between SES and prefrontal structure.

It is important to note that the identification of structural correlates of SES does not in any way imply that these SES differences are innate or unchangeable. Indeed, an emerging body of research demonstrates that structural brain measures (Draganski & May, 2008; Ilg et al., 2008; Keller & Just, 2009; Rosenzweig, 2003), including cortical thickness (Haier, Karama, Leyba & Jung, 2009) can be changed by environmental experience. It is our hope that identifying specific structural phenotypes that vary with socioeconomic status will lead to a better understanding of the mechanisms contributing to SES-disparities in health and achievement, and ultimately, will be used to design more effective policies and interventions that reduce these disparities.

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Disclaimer

This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH.

Figures:

Variable	n (%)	Mean (SD)
Age (in days)		4185.07 (1277.55)
Female	151 (53.36)	
Family Income Category		
<$5000	1 (.35)	
$5,001-$10,000	2 (.71)	
10,001-$15,000	3 (1.06)	
15,001-$25,000	7 (2.47)	
25,001-$35,000	10 (3.53)	
35,001-$50,000	47 (16.61)	
50,001-$75,000	68 (24.03)	
75,001-$100,000	77 (27.21)	
$100,001-$150,000	68 (24.03)	
over $150,000	0 (0)	
Family-size Adjusted Family Income		76169.13 (33022.32)
Maternal education		
Less than High School	2 (.71)	
High School	43 (15.19)	
Some College	78 (27.56)	
College	94 (33.22)	
Some Graduate Level	13 (4.59)	
Graduate Level	53 (18.73)	
Paternal education		
Less than High School	7 (2.47)	
High School	56 (19.79)	
Some College	74 (26.15)	
College	79 (27.92)	
Some Graduate Level	10 (3.53)	
Graduate Level	57 (20.14)	
Parental education		7.53 (2.31)
Parental education (square root transformed)		2.71 (.43)
Maternal race		
White	235 (83.04)	
African American/Black	23 (8.13)	
Asian	4 (1.41)	
American Indian/Alaskan Native	1 (.35)	
Native Hawaiian/Pacific Islander	0 (0)	
Multiple races listed	3 (1.06)	
Not provided	17 (6.00)	
Maternal ethnicity		
Not Hispanic or Latino	264 (93.29)	
Hispanic or Latino	19 (6.71)	
Paternal race		
White	222 (78.44)	
African American/Black	24 (8.48)	
Asian	5 (1.77)	
American Indian/Alaskan Native	2 (.71)	

Native Hawaiian/Pacific Islander	2 (.71)
Multiple races listed	8 (2.83)
Not provided	20 (7.07)
Paternal ethnicity	
Not Hispanic or Latino	259 (91.52)
Hispanic or Latino	24 (8.48)

Table 1: Summary of demographic information for the sample of 283 children with MRI data and

ROI	Model change when SES variables are added to the model		Regression coefficients for SES variables	
	R^2 change	F change (sig)	SES variable	Beta (sig)
Left inferior frontal gyrus	.004	.779 (.460)	Parental education Family income	-.085 (.215) .034 (.610)
Right inferior frontal gyrus	.005	.803 (.449)	Parental education Family income	-.065 (.338) -.017 (.803)
Left middle frontal gyrus	.001	.219 (.803)	Parental education Family income	.038 (.568) $7.34 * 10^{-4}$ (.991)
Right middle frontal gyrus	$9.38 * 10^{-5}$	.017 (.983)	Parental education Family income	.012 (.853) -.007 (.918)
Left superior frontal gyrus	.036	6.094 ($2.57 * 10^{-3}$)	Parental education Family income	.240 ($6.09 * 10^{-4}$) -.091 (.179)
Right superior frontal gyrus	.024	4.085 (.018)	Parental education Family income	.196 ($5.40 * 10^{-3}$) -.127 (.065)
Left anterior cingulate gyrus	.022	3.198 (.042)	Parental education Family income	.187 (.013) -.110 (.134)
Right anterior cingulate gyrus	.054	8.098 ($3.83 * 10^{-4}$)	Parental education Family income	.288 ($1.24 * 10^{-4}$) -.074 (.307)
Left orbitofrontal gyrus	$9.12 * 10^{-4}$	.138(.871)	Parental education Family income	-.022 (.769) -.017 (.814)
Right orbitofrontal gyrus	.002	.360 (.698)	Parental education Family income	-.029 (.702) -.034 (.638)
Inferior frontal asymmetry measure	0.006	.908 (.404)	Parental education Family income	-.051 (.509) .101 (.179)
Middle frontal asymmetry measure	0.003	.380 (.684)	Parental education Family income	.049 (.522) .015 (.841)
Superior frontal asymmetry measure	0.036	5.253 ($5.77 * 10^{-3}$)	Parental education Family income	.133 (.077) .109 (.137)

Table 2: Change in R^2 and change in F value for all ROIs after adding parental education and family income to the regression model. Standardized regression coefficient and p values are also shown for parental education and family income for each ROI.

Region of Interest (ROI):	Regression Step	R^2 change	F change (sig)	Beta (sig)
Left superior frontal gyrus	Model 1:	0.164	8.997 ($5.51 * 10^{-9}$)	
	Age			-.191 (.003)
	Gender (Female)			-.070 (.284)
	Total brain volume			-.214 ($1.98 * 10^{-3}$)
	BMI			-.147 (.023)
	IQ			.015 (.802)
	Race (White)			-.122 (.036)
	Model 2:	**0.036**	**6.094 ($2.57 * 10^{-3}$)**	
	Age			-.179 ($5.06 * 10^{-3}$)
	Gender (Female)			-.081 (.213)
	Total brain volume			-.210 ($2.06 * 10^{-3}$)
	BMI			-.138 (.029)
	IQ			-.044 (.479)
	Race (White)			-.144 (.013)
	Parental education			**.240 ($6.09 * 10^{-4}$)**
	Family income			-.091 (.179)
Right anterior cingulate gyrus	Model 1:	0.033	1.592 (.150)	
	Age			-.016 (.822)
	Gender (Female)			.021 (.767)
	Total brain volume			-.074 (.318)
	BMI			-.116 (.093)
	IQ			-.047 (.460)
	Race (White)			-.051 (.416)
	Model 2:	**.054**	**8.098 ($3.83 * 10^{-4}$)**	
	Age			-.004 (.957)
	Gender (Female)			.002 (.974)
	Total brain volume			-.071 (.325)
	BMI			-.104 (.125)
	IQ			-.129 (.055)
	Race (White)			-.081 (.187)
	Parental education			**.288 ($1.24 * 10^{-4}$)**
	Family income			-.074 (.307)

Table 3: Change in R^2, change in F and regression coefficients for hierarchical linear models for the right anterior cingulate gyrus and left superior frontal gyrus. SES variables were added in model 2, and significant SES effects are shown in bold.

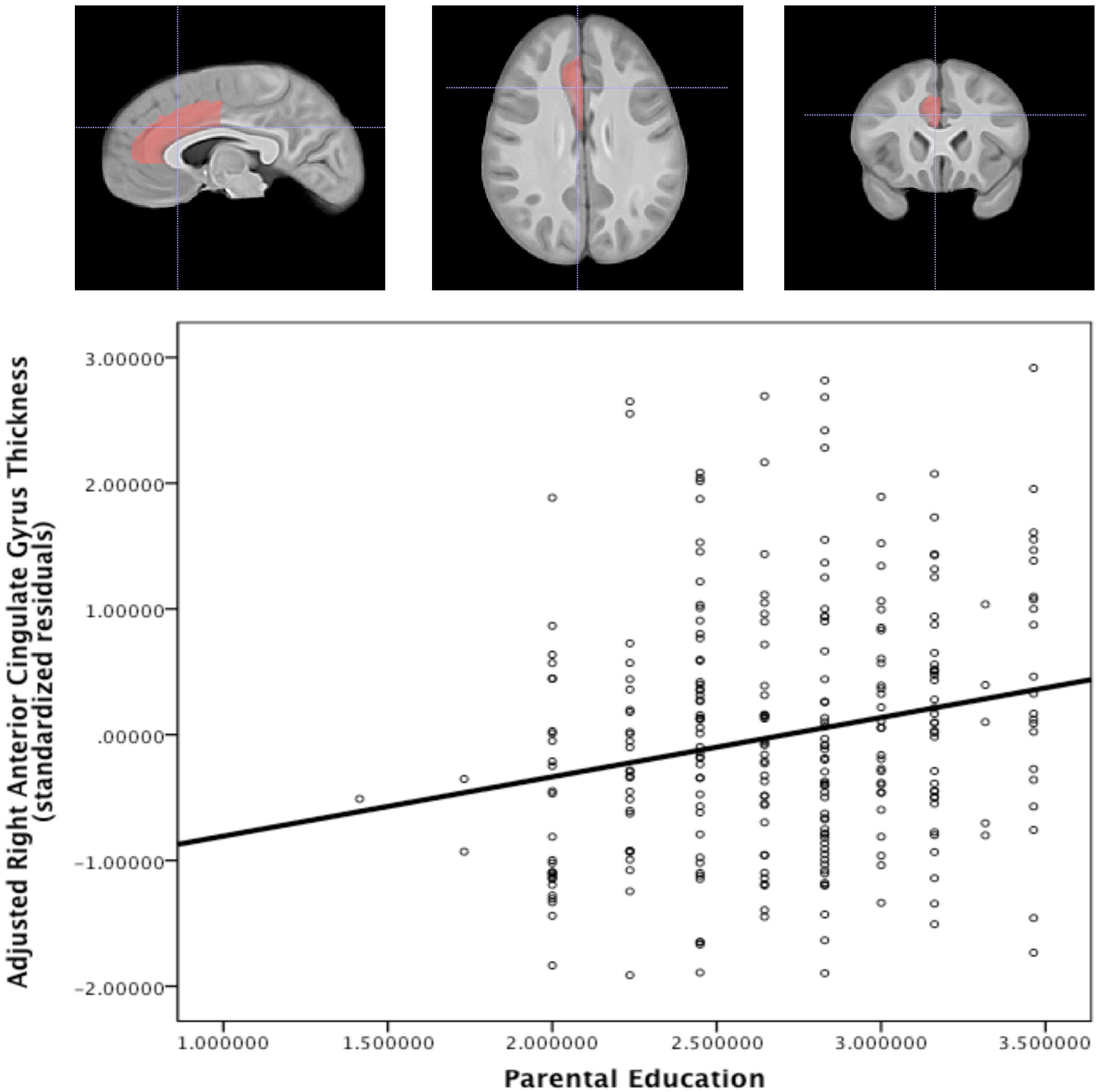

Figure 1: Scatterplot of right anterior cingulate gyrus thickness and parental education. This scatterplot shows the association between the square-root transformed parental education variable and cortical thickness in the right anterior cingulated gyrus. Cortical thickness was adjusted for age, total brain volume, gender, IQ, BMI and race by using the standardized residuals from a model in which these variables predict thickness.

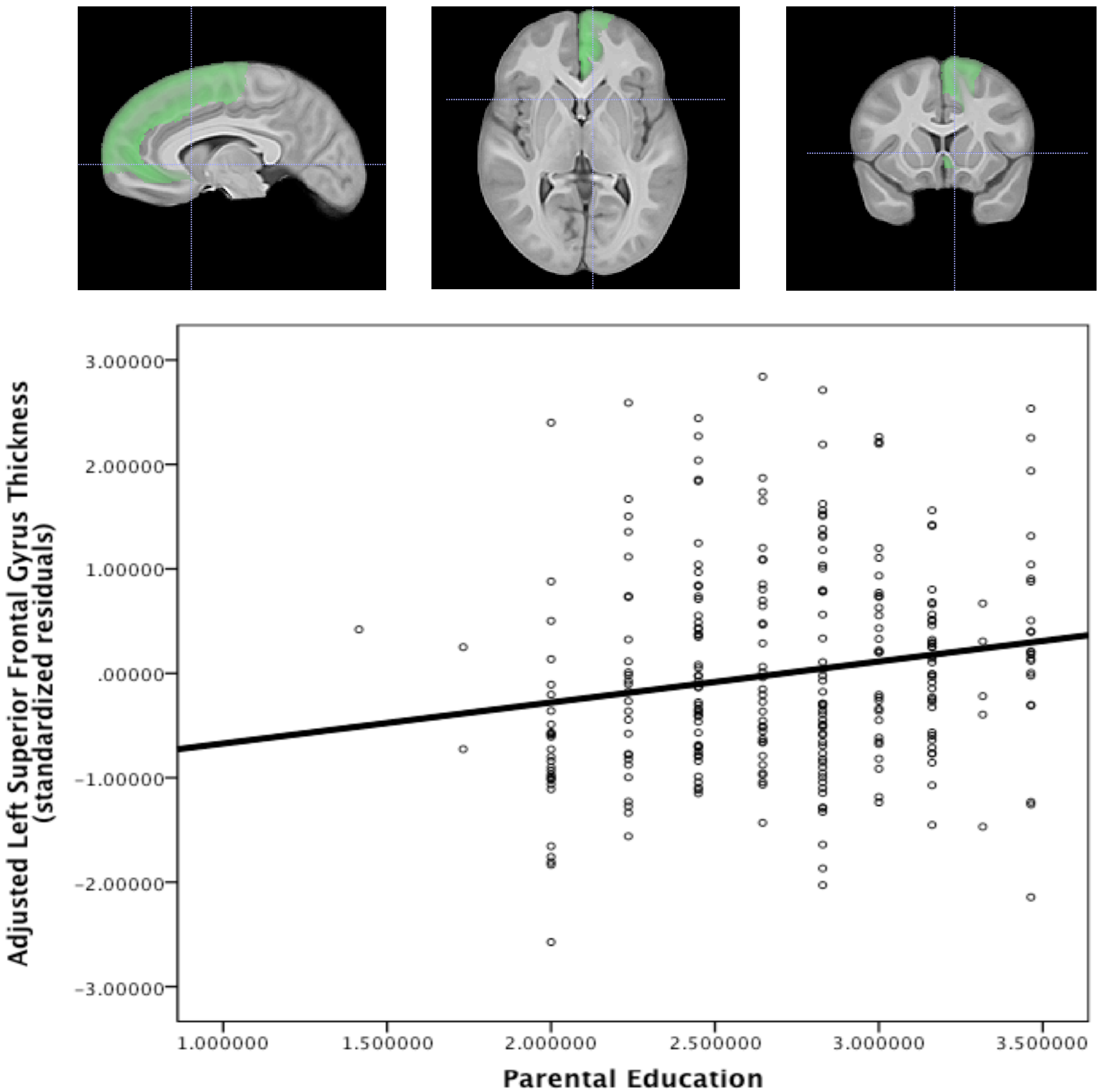

Figure 2: Scatterplot of left superior frontal gyrus thickness and parental education. This scatterplot shows the association between the square-root transformed parental education variable and thickness in the left superior frontal gyrus. Cortical thickness was adjusted for age, total brain volume, gender, IQ, BMI and race by using the standardized residuals from a model in which these variables predict thickness.

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