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School Climate is Associated with Cortical Thickness and Executive Function in Children and Adolescents

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Abstract

A positive school climate has been found to support mental and physical health, academic achievement and social adjustment among youth. However, links between school climate and brain structure have not been investigated to date. In this study, we investigated whether school climate was associated with executive function (EF) and brain structure (cortical thickness [CT] and surface area [SA]) in children and adolescents. We further examined whether these links varied as a function of socioeconomic background. Participants who ranged from 9 to 18 years of age ($N=108$) completed EF tasks and a high-resolution 3-Tesla T1-weighted magnetic resonance imaging (MRI) scan. Overall school climate, academic support, and family socioeconomic background were assessed using questionnaires. Higher academic support was associated with greater EF task performance and increased global CT. Additionally, academic support moderated the association between family income and EF, such that children from lower income families performed similarly to their more advantaged peers on EF tasks in the context of positive academic support. This work is the first to link school climate to brain structure and contributes to the growing body of evidence suggesting that academic support may be an important protective factor in the context of socioeconomic disadvantage.

Introduction

School climate encompasses multiple aspects of the educational experience from a student or staff member perspective (Thapa, Cohen, Guffey, & Higgins-D'Alessandro, 2013), including academic support, the quality of relationships with teachers and peers, school safety, and structural organization (Zullig, Koopman, Patton, & Ubbes, 2010). While other aspects of school quality are commonly investigated through observational measures (Allen et al., 2013; Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Buell & Cassidy, 2001; Downer, Booren, Lima, Luckner, & Pianta, 2010; Harms, Clifford, & M., 1980; Harms, Clifford, & Cryer, 1998; La Paro, Pianta, & Stuhlman, 2004; Raver et al., 2011; Raver et al., 2009; Ursache, Blair, & Raver, 2012), school climate research typically focuses on students'

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and/or staff members' *perception* of the school context in terms of the quality of support for learning and achievement as well as the quality of the school community, safety, and structural organization (Jia et al., 2009; Novak & Clayton, 2001; Patrick, Ryan, & Kaplan, 2007; Raver, McCoy, Lowenstein, & Pess, 2013; Roeser, Eccles, & Sameroff, 2000).

A supportive school climate has been positively associated with mental and physical health (Cohen, McCabe, Michelli, & Pickeral, 2009; Denny et al., 2011; Gilstad-Hayden et al., 2014; LaRusso, Romer, & Selman, 2008; Shochet, Dadds, Ham, & Montague, 2006; Wang, 2009; Way, Reddy, & Rhodes, 2007) and academic achievement (Bond et al., 2007; Brand, Felner, Seitsinger, Burns, & Bolton, 2008; Sherblom, Marshall, & Sherblom, 2006; Wang & Holcombe, 2010), and has been associated with reduced rates of risky sexual behavior, violence, and drug use (Catalano, Oesterle, Fleming, & Hawkins, 2004; LaRusso et al., 2008; Wang, Selman, Dishion, & Stormshak, 2010). These findings raise questions about the ways in which school climate may be associated with more specific underlying neurocognitive skills as well as the developing brain.

School Climate Construct

School climate has been defined as a multifaceted construct involving four domains: academic, community, safety, and institutional environment (Wang & Degol, 2016). Of these, the academic domain, referring to the ways in which learning and teaching are promoted in the school, is the most commonly studied and perhaps the most salient dimension of school climate (Wang & Degol, 2016). More specifically, this component of school climate refers to teacher support for learning and the way that instructional practices, including curriculum, teaching expectations, and student evaluation, facilitate learning experiences (Jia et al., 2009; Thapa et al., 2013). Academic support has been found to be particularly important for academic achievement (Jia et al., 2009; Thapa et al., 2013), and is the strongest predictor of school satisfaction (Zullig, Huebner, & Patton, 2011).

School Climate and Children's Executive Function

Executive function (EF) is defined as a set of neurocognitive skills that support flexible, goal-directed behavior (Hofmann, Schmeichel, & Baddeley, 2012; King, Lengua, & Monahan, 2013). EF is composed of three core components (Blair, 2016; Diamond, 2013; Miyake et al., 2000): inhibitory control, or the ability to suppress an automatic or dominant response (Diamond, 2013; Hofmann et al., 2012); working memory, or the ability to hold and manipulate information in mind (Baddeley & Hitch, 1994); and cognitive flexibility, or the ability to adjust to novel situations and shift among cognitive strategies (Diamond, Barnett, Thomas, & Munro, 2007). A supportive school climate has been found to promote the development of self-regulatory constructs similar to EF (Novak & Clayton, 2001; Patrick, Ryan, Kaplan, 2007; Wang, 2009; Wang & Holcombe, 2010; Raver et al., 2013). Less is known about school climate in relation to direct assessments of EF.

School Climate and Children's Brain Structure

EF has a protracted developmental course that begins in childhood and continues through adolescence and early adulthood (Romine & Reynolds, 2005; Welsh, Pennington, & Groisser, 1991). This developmental trajectory corresponds in part to structural changes in

regions of the prefrontal cortex (PFC). Many structural neuroimaging studies have focused on cortical volume, which is a composite of cortical thickness (CT) and surface area (SA). Recently, CT and SA have been revealed to be genetically, phenotypically, and developmentally independent, reinforcing the importance of studying them separately (Panizzon et al., 2009; Raznahan et al., 2011; Wierenga, Langen, Oranje, & Durston, 2014). The cortex thins rapidly in childhood and early adolescence and then follows a slower thinning process throughout early adulthood, reaching a plateau in middle-adulthood (Raznahan et al., 2011; Schnack et al., 2014; Sowell et al., 2007; Sowell et al., 2003; Zhou, Lebel, Treit, Evans, & Beaulieu, 2015). In contrast, cortical SA tends to increase through childhood and early adolescence and decrease in adulthood (Raznahan, 2011).

Both CT and SA in the PFC have been linked with variability in children's EF. For example, cortical thinning has been related to better EF task performance (Kharitonova, Martin, Gabrieli, & Sheridan, 2013; Squeglia, Jacobus, Sorg, Jernigan, & Tapert, 2013; Tamnes et al., 2010). In addition, greater cortical SA has been associated with better EF task performance across childhood and adolescence (Noble et al., 2015; Østgård et al., 2016). To our knowledge, no studies to date have examined the associations between school climate and children's brain structure. This is surprising, as the protracted development of the PFC likely increases its susceptibility to environmental influences such as school climate (Casey, Getz, & Galvan, 2008; Casey, Giedd, & Thomas, 2000; Farah et al., 2006; Hackman & Farah, 2009; Hackman, Farah, & Meaney, 2010; King et al., 2013; Romine & Reynolds, 2005; Steinberg, 2005).

The Role of School Climate in Relation to Socioeconomic Background and EF

It is well-established that family socioeconomic background is associated with children's EF development, and more recent studies have revealed robust links between socioeconomic background and children's brain structure, including CT (Brito & Noble, 2014; Brito, Piccolo, & Noble, 2017; Butterworth, Cherbuin, Sachdev, & Anstey, 2011; Cavanagh et al., 2013; Hair, Hanson, Wolfe, & Pollak, 2015; Hanson, Chandra, Wolfe, & Pollak, 2011; Jednorog, 2012; Lawson, Duda, Avants, Wu, & Farah, 2013; Luby et al., 2012; Mackey et al., 2015; Noble et al., 2015; Noble, Houston, Kan, & Sowell, 2012; Piccolo, Merz, He, Sowell, & Noble, 2016; Schnack et al., 2014; Shaw et al., 2006; Staff et al., 2012) and SA (Noble et al., 2015; Østgård et al., 2016). These findings raise questions about which factors may mediate and/or moderate socioeconomic differences in children's EF and brain structure. Researchers have identified several factors that may mediate or moderate these differences, including stressful life events (Luby et al., 2013) and positive parenting (Whittle, Vijayakumar, Simmons, & et al., 2017). However, it is unknown whether socioeconomic disparities in children's EF and brain structure may be mediated or moderated by school climate.

As children and adolescents spend a large proportion of their time in school, school climate is poised to produce particularly strong effects on brain development. One possibility is that school climate partially mediates associations of socioeconomic background with EF and brain structure. Indeed, children living in disadvantaged neighborhoods are more likely to attend lower quality schools (DeLuca & Dayton, 2009), which may in turn influence their

brain development and EF skills. Another possibility is that school climate acts as a moderator (Hopson & Lee, 2011; O'malley, Voight, Renshaw, & Eklund, 2015). For example, it has been suggested that the negative effects of less-supportive school climates may be magnified in the context of socioeconomic disadvantage (Downey, von Hippel, & Broh, 2004).

Current Study

The goal of the present study was to examine the associations among socioeconomic background, school climate, cortical structure, and EF. Children and adolescents, ranging in age from 9 to 18 years ($N = 108$), reported on their perceptions of school climate. They also completed inhibitory control, working memory, and cognitive flexibility tasks, and participated in a high-resolution T1-weighted structural magnetic resonance imaging (MRI) scan. Analyses focused on global CT and SA; exploratory vertex-wise analyses were also conducted.

Specific research questions were as follows. First, is school climate associated with children's EF skills? Second, how does school climate relate to global and regional CT and SA? Third, are socioeconomic disparities (family income, parental education) in EF, CT and SA mediated or moderated by school climate? Family income and parental education were examined separately, rather than averaging them into an SES composite, as they represent distinct features of children's environments with differential contributions to child development (Duncan & Magnuson, 2012).

Method

Participants

Data used in this study came from the multi-site Pediatric Imaging, Neurocognition, and Genetics (PING) study (<http://ping.chd.ucsd.edu>) (Jernigan et al., 2016). PING participants were recruited at nine university-based data collection sites in or around the cities of Los Angeles, San Diego, New Haven, Sacramento, San Diego, Boston, Baltimore, Honolulu, and New York. Exclusionary criteria included a history of neurological, psychiatric, medical, or developmental disorders. Participants and their parents gave their informed written consent/assent to participate in all study procedures. Each data collection site's Office of Protection of Research Subjects and Institutional Review Board approved the study.

Web-based, self-report assessments from the PhenX Toolkit (<https://www.phenxtoolkit.org>) were administered at six of the nine PING sites (Jernigan et al., 2016; McCarty et al., 2014). This assessment battery included a questionnaire focused on school climate (described below). The current study includes the 108 children and adolescents for whom complete data on school climate, socioeconomic factors, CT, SA, and EF were available (see Table 1 for full sample characteristics). This subsample of 108 youth did not differ significantly from the larger PING sample in terms of sociodemographic background [parental education ($t(1097) = .76$; $p = .45$); family income ($t(1097) = 1.21$; $p = .23$); genetic ancestry factor (GAF) ($\chi^2(6) = 2.83$, $p = 0.83$); gender ($\chi^2(1) = 2.07$, $p = 0.15$)].

Measures

School climate.—The School Social Environment Scale (Zullig et al., 2010) assesses students' perceptions of the quality and character of their school environment, henceforth termed “school climate”. The scale can be administered to children and adolescents from 9 to 18 years old (Zullig et al., 2010). This self-report questionnaire includes 39 items, which are rated on a 5-point scale ranging from 0 (*strongly disagree*) to 4 (*strongly agree*). It includes eight subscales: academic support (6 items), teacher relationships (9 items), school connectedness (6 items), order and discipline (7 items), school physical environment (4 items), school social environment (2 items), perceived exclusion/privilege (3 items), and academic satisfaction (2 items). Based on previous work summarized above (Jia et al., 2009; Thapa et al., 2013; Wang & Degol, 2016; Zullig et al., 2011), we hypothesized that the academic support subscale would be most relevant for addressing questions about links among school climate, socioeconomic disparities and EF. We therefore focused our analyses on the academic support subscale, which included questions such as “Teachers make it clear what work needs to be done to get the grade I want;” “I believe that teachers expect all students to learn;” and “My teachers believe that I can do well in my school work”. Exploratory analyses also considered the total school climate score, as well as one subscale that we did *not* hypothesize would be associated with our outcomes of interest, namely the school physical environment subscale. The School Social Environment Scale has shown strong psychometric properties in previous research (Zullig et al., 2010).

Socioeconomic status.—Parents reported the total yearly family income and the levels of parental educational attainment. Parental education in years was averaged across parents in the household. Both education and income data were originally collected in bins, which were recoded as the means of the bins for analysis (Noble et al., 2015). Family income was natural log-transformed to correct for a positively skewed distribution.

Executive function (EF).—Children completed the list sorting working memory, flanker, and dimensional change card sort (DCCS) tasks from the NIH Toolbox Cognition Battery (Akshoomoff, 2014). Scores on these tasks were strongly correlated ($r = .45 - .57, p < 0.0001$). An EF composite score was calculated by averaging the z-scores of these three EF tasks.

Working memory.: On the list sorting working memory test, a series of pictures of different foods and animals were presented on a computer screen visually and aurally, one at a time. In the one-list condition, participants were told to remember stimuli from one category (food or animals) and repeat them in size order, from smallest to largest. In the two-list condition, participants were told to remember stimuli from two categories (food and animals, intermixed) and then report the food in size order, followed by the animals in size order. Working memory scores consisted of the total items correct across the one- and two-list conditions.

Inhibitory control.: On the flanker task, participants were asked to focus on the central stimulus while inhibiting attention to the flanker (surrounding) stimuli. The test consisted of a block of 25 fish trials followed by a block of 25 arrow trials, with 16 congruent and 9

incongruent trials in each block, presented in pseudorandom order. On congruent trials, all the stimuli were pointing in the same direction (right or left). On incongruent trials, the central stimulus was pointing in the opposite direction of the flanker stimuli. Congruent and incongruent trials were intermixed in each block of test trials. Performance on both congruent and incongruent trials was recorded. A two-vector scoring method was used that incorporated both accuracy and reaction time (RT) for participants who maintained a high level of accuracy (>80% correct), and accuracy only for those who did not meet this criterion.

Cognitive flexibility.: On the dimensional change card sort (DCCS) task, children view a series of target pictures that vary along two dimensions (e.g., shape and color). They are asked to match test pictures (e.g., yellow trucks and red balls) to the target pictures, first according to one dimension (e.g., color) then according to the other dimension (e.g., shape). During the “switch” trials, participants must adjust their performance to dimensional changes, for example, alternating between matching on color and shape. A two-vector scoring method was used that incorporated both accuracy and RT for participants who maintained a high level of accuracy (>80% correct), and accuracy only for those who did not meet this criterion.

Genetic ancestry factor (GAF)

As described in detail previously (Akshoomoff, 2014; Fjell et al., 2012), genomic DNA was genotyped with Illumina Human660W-Quad BeadChip and replication and quality control filters (sample call rate >99, call rates >95%, minor allele frequency >5%) were performed (Bakken, 2012). A supervised clustering approach implemented in the ADMIXTURE software was used to assess genetic ancestry and admixture proportions in the PING participants (Alexander & Lange, 2011). Through this approach, GAFs were developed for each participant, representing the proportion of ancestral descent for each of six major continental populations: African, Central Asian, East Asian, European, Native American and Oceanic. GAF and participant-reported race were strongly correlated in the PING sample (Akshoomoff, 2014).

Image Acquisition and Processing

Detailed information about the standardized structural MRI protocol and the pre- and post-processing techniques have been reported previously (Fjell et al., 2012). In brief, high-resolution 3D T1-weighted images were acquired (see Table S1 for scanner models and parameters). MRI data were submitted to a standardized quality-image check, with no manual editing of images deemed acceptable for inclusion in the database (see Jernigan, Brown, Bartsch, & Dale, 2016 for details). Image analyses were performed using a modified FreeSurfer software suite (<http://surfer.nmr.mgh.harvard.edu/>) to obtain measures of surface-based cortical anatomy, including CT and SA (Fischl & Dale, 2000).

Statistical Analyses

Descriptive statistics and zero-order correlations were first conducted. To adjust for outliers, all outcome variables (CT, SA and EF) were Winsorized when data points were greater than three standard deviations from the mean. In addition, Mahalanobis distance, Cook's

distance, and leverage values were calculated for the dependent variables based on independent variables (SES, school climate) to identify outliers, and two outliers were excluded from analyses. Because both CT and SA develop in nonlinear patterns (Mills & Tamnes, 2014), both linear and quadratic terms for age were included in models with CT and SA as outcomes. Quadratic terms that were not significant or marginally significant ($p < .10$) were dropped from the final models.

To examine whether school climate was associated with EF, multiple linear regression models were conducted controlling for age, sex, and GAF. Of note, when controlling for parent/self-reported race/ancestry, results remained the same as those controlling for GAF. Similarly, multiple linear regression analyses were conducted to investigate the associations between school climate and CT and SA, controlling for age (both linear and quadratic terms), sex, scanner, and GAF. Dependent variables included both average CT and total SA. Exploratory whole-brain vertex-wise analyses of CT and SA were additionally conducted, with vertex-wise significance set to $p < .001$.

Then, we examined whether socioeconomic disparities in EF, CT and SA were mediated or moderated by school climate. To do so, we first ran separate multiple regression models to investigate whether socioeconomic factors (parental education, family income) were associated with children's EF, CT and/or SA. Models of EF controlled for age, sex, and GAF. Models of SA and CT additionally controlled for scanner and both the linear and quadratic terms for age. Bias-corrected confidence intervals were generated from bootstrap mediation models to test the significance of indirect effects (Preacher & Hayes, 2008). Moderation analyses examined interactions between school climate and SES factors. Significant interactions were probed using the Johnson-Neyman technique (Johnson & Neyman, 1936) and simple slopes analysis. To adjust for multiple comparisons, we applied false discovery rate (FDR) corrections ($p < .05$). All analyses were performed using SPSS version 24. Mediation and moderation analyses were conducted using the PROCESS macro (Hayes, 2015).

Results

Academic Support is Associated with Children's EF

Higher academic support was associated with the higher EF performance ($\beta = .23$, $p = .011$, $Adj. R^2 = .33$), as shown in Table 2. Neither the school climate total score nor the school physical environment subscale score were associated with EF performance.

Academic Support is Associated with Average Cortical Thickness

Higher academic support was associated with higher average whole-brain CT, controlling for age, age², sex, scanner and GAF (see Table 3). This association remained significant even after controlling for parental education ($\beta = 0.19$; $p = 0.030$) and family income ($\beta = 0.19$; $p = 0.033$). Academic support was not related to total SA. Neither the school climate total score nor the school physical environment subscale score were related to CT or SA. Additionally, cortical thickness was not related to EF performance.

Academic Support Moderated the Link between Family Income and Executive Function

Mediation results.—Higher family income, but not parental education, was significantly associated with better EF task performance (see Table 2 and Table S2 for the association between SES factors and each EF task). As previously reported in the full PING sample (Noble et al., 2015), higher family income was associated with higher total SA ($\beta = .20$, $p = .022$, $Adj. R^2 = .33$), but was not significantly associated with average CT. Parental education was not related to CT or SA. However, neither family income ($p = .59$) nor parental education ($p = .30$) were associated with academic support (or with total school climate or the school physical environment). Thus, school climate did not significantly mediate socioeconomic disparities in children's EF or total CT or SA.

Moderation results.—There was a significant interaction between academic support and family income for EF task performance ($\beta = -.22$, $p = .002$, $Adj. R^2 = .33$) (see Table 2). As shown in Figure 1, at high levels of family income, children generally had high EF performance, regardless of academic support. However, at lower levels of family income, children with lower levels of academic support performed poorly, whereas children with high levels of academic support demonstrated preserved EF task performance. Probing this interaction further, Johnson-Neyman analyses indicated significant associations between academic support and EF for family income values less than \$67,500. Examination of the simple slopes revealed that for low academic support ($-1 SD$) ($b = 1.43$, $t(93) = 4.07$, $p = .0001$) and average academic support ($b = .88$, $t(93) = 3.73$, $p = .0003$), higher family income was significantly associated with better EF. However, for high academic support ($+1 SD$), family income was not significantly associated with EF ($b = .33$, $t(93) = 1.01$, $p = .32$).

There were no significant interactions between parental education and academic support for EF, nor were there significant interactions between SES indices and either total school climate or school physical environment for EF, CT, or SA.

Exploratory moderation analyses for each EF component.—Exploratory analyses revealed a significant interaction between academic support and family income for children's inhibitory control ($\beta = -.26$, $p = .008$, $Adj. R^2 = .15$) (see Table 4). Similar to the results for the EF composite, for high levels of family income, children generally showed high levels of inhibitory control, regardless of academic support. On the other hand, for children from economically disadvantaged families, those with lower levels of academic support had lower inhibitory control scores, while children with high levels of academic support demonstrated inhibitory control at levels similar to children from the most advantaged families. Johnson-Neyman analyses indicated significant associations between academic support and inhibitory control for family income values less than \$56,000. Examination of the simple slopes revealed that for low ($-1 SD$) ($b = .43$, $t(94) = 3.74$, $p = .0003$) and average ($b = .21$, $t(94) = 2.75$, $p = .007$) academic support, higher family income was significantly associated with better inhibitory control. However, for high ($+1 SD$) ($b = -.004$, $t(94) = -.03$, $p = .97$) academic support, family income was not significantly associated with children's inhibitory control.

Exploratory Whole-Brain Analyses

Exploratory whole-brain vertex-wise analyses of CT were conducted using the PING portal (<http://pingstudy.ucsd.edu/>) (Bartsch, Thompson, Jernigan, & Dale, 2014). We examined associations with academic support, while adjusting for age, age², sex, GAF, and scanner. For significance evaluated at $p < .05$, FDR-corrected, no significant clusters emerged for academic support. We then mapped, at each vertex, the uncorrected p -value associated with academic support for CT. Regions that were associated with academic support at a threshold of $p < .001$, uncorrected (a threshold that protects against false negatives), are presented in Figure S1, S2 and S3 (see Supplementary Materials). These tended to be in the bilateral occipital lobes and the right posterior temporal lobe, similar to findings of Mackey et al. (2015). This approach was not intended for hypothesis-testing but rather to inform future research by showing the magnitude and direction of differences in regions failing to pass FDR correction for multiple comparisons.

Discussion

The school environment plays an important role in children's cognitive development and educational outcomes. School climate has been identified as a powerful multidimensional construct associated with children's mental and physical health (Cohen et al., 2009; Denny et al., 2011; Gilstad-Hayden et al., 2014; LaRusso et al., 2008; Maxwell, Reynolds, Lee, Subasic, & Bromhead, 2017; Shochet et al., 2006; Thapa et al., 2013; Wang, 2009; Way et al., 2007) and academic achievement (Bond et al., 2007; Brand et al., 2008; Wang & Holcombe, 2010). The goals of this study were to examine associations of school climate with children's cortical structure (cortical thickness and surface area) and EF, and to explore the role of school climate as a mediator or moderator of socioeconomic differences in cortical structure and EF. We focused on academic support, a core school climate domain that plays a particularly important role in youth health and achievement outcomes (Jia et al., 2009; Thapa et al., 2013; Zullig et al., 2011).

Results indicated that higher perceived academic support was associated with increased EF performance, as well as increased average cortical thickness across the brain. We did not find significant regionally-specific effects after FDR correction using a vertex-wise approach. Additionally, there were no associations between school climate and cortical surface area. To our knowledge, this is the first study to report an association between school climate and cortical thickness.

Some studies have found associations between cortical thickness and cognitive skills, but the directionality of associations has been inconsistent. Changes in cortical thickness may reflect synaptic pruning or myelination (Paus, 2005), which in animal models have been associated with differences in cognitive stimulation or "environmental enrichment" (Greenough, Black, & Wallace, 1987; Tierney & Nelson, 2009). One possibility is that early adversity may accelerate development (Callaghan & Tottenham, 2016); the results of the present study may be consistent with this notion, suggesting that high academic support may allow for a more protracted course of cortical thinning (and thus be associated with thicker cortices at a single point in time). This is speculative, however, and the mechanisms through which school climate may be associated with brain development require further investigation

using longitudinal studies. In addition, future investigations with larger samples will be necessary to determine whether this is truly a nonspecific effect across the entire cortex, or whether we simply had limited statistical power to detect regional effects, as hinted at in our exploratory analyses that were uncontrolled for multiple comparisons. We emphasize caution in interpreting this finding, considering that our data are cross-sectional and questions about developmental trajectories are better addressed with longitudinal designs (Kraemer, Yesavage, Taylor, & Kupfer, 2000).

Results also indicated that academic support moderated the association between family income and EF, such that the risk for EF difficulties among children from socioeconomically disadvantaged families was mitigated among those who reported high levels of academic support in school. This finding is consistent with previous work that has linked school climate with self-regulatory constructs similar to EF (Novak & Clayton, 2001; Patrick et al., 2007). Additionally, this result is in line with past work suggesting that the school environment may play a role in exacerbating or ameliorating socioeconomic disparities in cognitive development (Downey et al., 2004; Hopson & Lee, 2011). This work also complements previous research identifying positive parenting as a potential protective factor (Whittle et al., 2017), suggesting that aspects of both the home and school environments may modify the effects of socioeconomic circumstances on children's development. School environments may serve as an equalizer of socioeconomic inequality, likely because variations in experience inside the school context may be smaller than those out of school (Downey et al., 2004). In this sense, schools with high levels of academic support – and where students perceive that teachers have high expectations for their academic success – may help children and adolescents overcome the consequences of living in disadvantaged environments. Of course, in a correlational study, we cannot be certain of the direction of effect, and an alternative explanation could be that children from lower-income families with strong EF skills may elicit more academic support from their teachers. Teachers tend to have higher expectations and affinity – and consequently may be more likely to support – children who have better EF (Duckworth & Seligman, 2005; Graziano, Reavis, Keane, & Calkins, 2007; Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008; Willingham, 2011).

Results suggested that the interaction between academic support and family income for the EF composite may be attributable to inhibitory control aspects of the EF tasks. Indeed, when the EF components were examined separately, the interaction was only significant for inhibitory control (see Table 4). This finding is consistent with work showing that academic support moderates the association between adverse environments and social behavior, given that inhibitory control has been related to social functioning (Gray, Chabris, & Braver, 2003; Rueda, Checa, & Rothbart, 2010)

Several limitations should be considered when interpreting these results. The measure of school climate was a self-report measure, and thus could be biased by student's perceptions in a way that an objective, observational measure would not. Further, there are other aspects of the school environment (i.e., infrastructure, neighborhood), for which we lack data, and which may well be involved in cognitive and brain structural outcomes. Future studies should also include multiple potential mitigating factors, such as positive parenting (Whittle et al., 2017) and other protective and stimulating relationships (Shonkoff, 2010), to examine

their unique contributions in terms of ameliorating socioeconomic disparities in children's development.

Despite these limitations, this study contributes to the growing body of evidence suggesting that school-based academic support may be an important factor for child development, including brain development. Additionally, these findings extend our understanding of environmental moderators of socioeconomic disparities in brain and EF development, and provide insight into possible mechanisms underlying associations between childhood experiences and neurodevelopment. One possible path to overcoming the deleterious effects of socioeconomic disadvantage on brain and cognitive development may be through increasing academic support in schools.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Research Highlights

- Higher academic support was associated with increased executive function and average cortical thickness in children and adolescents.
- Children and adolescents from disadvantaged families performed similarly to their more advantaged peers on executive function tasks in the context of positive academic support.
- These findings suggest that academic support may mitigate the effects of socioeconomic disadvantage on executive function.

Figure 1.

Associations between family income and EF task performance at low, middle and high levels of academic support. All analyses were performed using continuous variables for family income (log-transformed), EF performance and academic support, but results are displayed in three academic support groups (mean, ± 1 SD). Academic support moderated the association between family income and EF task performance, controlling for age, sex and GAF. Lower family income was associated with lower EF among children reporting lower and middle levels of academic support (the association between academic support and EF was statistically significant for family income values less than \$67,500).

Table 1
Descriptive Statistics for Sample Characteristics, Executive Function, and Cortical Structure (N = 108)

	<i>M (SD) or n (%)</i>	Range
Age in years	14.10 (1.76)	9.32 – 17.56
Sex (male)	63 (58.3%)	
Parental education in years	15.42 (2.12)	8 – 18
Family income in U.S. dollars	89,944.44 (63513.39)	4,500 – 325,000
Genetic ancestry factor (GAF)		
African	0.10 (0.30)	
American Indian	0.02 (1.4)	
Central Asian	0.01 (0.10)	
East Asian	0.16 (0.40)	
European	0.60 (0.50)	
Oceanic	0	
List sorting working memory task	20.62 (2.55)	12-26
Flanker inhibitory control task	8.52 (0.69)	5.90 – 9.75
Dimensional change card sort task	8.31 (0.64)	6.30 – 9.94
Average cortical thickness (mm)	2.73 (.123)	2.40 – 3.07
Total cortical surface area (mm ²)	172496.69 (12060.75)	130674 - 219228

Table 2
Academic Support Moderates the Association between Family Income and EF

	<i>Adj R² = .33</i>		
	<i>B</i>	<i>t</i>	<i>p</i>
Age	.357	4.047	.000
Sex	-.063	-.723	.471
GAF African	-.131	-1.487	.140
GAF American Indian	.116	1.300	.197
GAF East Asian	.222	2.558	.012
GAF Central Asian	.157	1.833	.070
Academic support	.228	2.407	.011
Family income	.346	3.851	.000
Family income × academic support	-.218	-2.287	.002

Note. GAF = genetic ancestry factor.

Table 3
Association between Academic Support and Whole-Brain Average Cortical Thickness

	<i>Family income model</i>			<i>Parental education model</i>		
<i>Adj R²</i>	<i>.30</i>			<i>.29</i>		
	<i>B</i>	<i>t</i>	<i>p</i>	<i>B</i>	<i>t</i>	<i>p</i>
Age	-.739	-1.009	.316	-.882	-.679	.499
Age ²	.227	.627	.532	.376	.290	.772
Sex	-.043	-.493	.623	-.069	-.797	.428
Scanner 1	.005	.047	.962	.000	-.002	.998
Scanner 2	.026	.286	.775	.015	.172	.864
Scanner 3	-.235	-2.470	.015	-.259	-2.721	.008
Scanner 4	.053	.615	.540	.060	.683	.496
Scanner 5	-.036	-.282	.779	-.024	-.187	.852
Scanner 6	-.188	-1.786	.078	-.183	-1.710	.091
Scanner 7	-.153	-1.543	.127	-.152	-1.525	.131
Scanner 8	-.132	-.991	.324	-.126	-.926	.357
GAF African	.028	.292	.771	.043	.447	.656
GAF American Indian	-.206	-1.782	.078	-.220	-1.833	.070
GAF East Asian	-.132	-.976	.332	-.144	-1.050	.297
GAF Central Asian	-.137	-1.290	.201	-.145	-1.310	.194
Academic support	.187	1.935	.021	.205	2.366	.020
SES variable	.112	1.233	.221	.261	.695	.489
Academic support × SES variable	.045	.449	.655	-.250	-.663	.509

Note. GAF = genetic ancestry factor; SES = socioeconomic status.

Table 4
Academic Support Moderates the Association between Family Income and Inhibitory Control

	Working Memory			Inhibitory Control			Cognitive Flexibility		
	<i>B</i>	<i>t</i>	<i>p</i>	β	<i>t</i>	<i>p</i>	β	<i>t</i>	<i>p</i>
Age	.14	1.454	.149	.27	2.85	.005	.33	3.620	.000
Sex	-.23	-2.378	.019	-.03	-.27	.787	.03	.285	.776
GAF African	-.14	-1.491	.139	-.09	-.92	.358	-.09	-1.048	.297
GAF American Indian	.13	1.296	.198	.13	1.34	.182	.04	.418	.677
GAF East Asian	.02	.199	.843	.10	1.04	.300	.33	3.714	.000
GAF Central Asian	.10	1.029	.306	.09	1.04	.302	.16	1.819	.072
Academic support	.23	2.210	.021	.15	1.59	.114	.09	.997	.322
Family income	.24	2.451	.016	.28	2.85	.005	.26	2.789	.006
Family income $\times$ academic support	-.09	-.968	.335	-.26	-2.71	.008	-.10	-1.066	.289

Note. GAF = genetic ancestry factor.