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Association Between Altitude and Regional Variation of ADHD in Youth

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Abstract

Objective—The purpose of this study was to evaluate the effect of altitude on rates of ADHD. As decreased dopamine (DA) activity has been reported with ADHD and hypoxia has shown to be associated with increased DA, we hypothesized that states at higher altitudes would have lower rates of ADHD.

Method—State estimates from the 2007 National Survey of Children's Health (NSCH) report and 2010 National Survey of Children with Special Health Care Needs (NS-CSHCN) report were used to extract the percentages of youth ages 4 to 17 diagnosed with ADHD.

Results—Both the datasets independently revealed that the prevalence of ADHD decreases with increasing altitude ($R^2 = .38, p < .001$; $R^2 = .31, p < .001$), respectively. This study controlled for potential confounds (e.g., low birth weight, ethnicity, and household size).

Conclusion—These findings suggest a need for further investigation into the extent by which altitude may serve as a protective factor for ADHD.

Keywords

altitude; ADD/ADHD; hypoxia; NSCH; geographic variation

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Declaration of Conflicting Interests

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Introduction

ADHD is the most prevalent psychiatric disorder of childhood and is characterized by inattention, impulsivity, and hyperactive behavior (American Psychiatric Association, 2000). Symptoms of inattention and hyperactivity may cause significant clinical impairment in social, academic, and occupational functioning of individuals with ADHD. Children and adolescents with ADHD often have difficulty with schoolwork and social relationships (Strine et al., 2006). For many youth, ADHD persists into adulthood and adults with ADHD are at increased risk of unemployment, divorce, substance use, and serious motor vehicle accidents (American Psychiatric Association, 2000).

Findings from the National Survey of Children's Health (NSCH) conducted in 2003 and 2007 show that ADHD has a considerable impact on public health, affecting as many as 11% of children (Visser et al., 2013). According to Visser and colleagues (2013), between 2003 and 2011, there was a 42% increase in the number of youth ages 4 to 17 who were diagnosed with ADHD. The annual medical costs incurred by children with ADHD (US \$4,306) are more than double that of children without ADHD (US\$1,944; Leibson, Katusic, Barbaresi, Ransom, & O'Brien, 2001). Moreover, the combined economic impact of pediatric and adult ADHD in the United States is estimated to be at least US\$143 billion per year, and may be as much as US\$266 billion annually (Doshi et al., 2012).

It is well known that rates of ADHD differ by gender, race, and ethnicity (Martel, 2013; Schneider & Eisenberg, 2006). Non-Hispanic White and Black children are more likely to have a diagnosis of ADHD than Hispanic children (Pastor & Reuben, 2008). In addition, the odds of being diagnosed with ADHD are increased with depression, anxiety, two-parent households, and health care coverage (Hinojosa et al., 2012; Pastor & Reuben, 2008). Genetic influences play an important role in the etiology of ADHD, as shown by twin studies that have reported 60% heritability (Wood, Buitelaar, Rijdsdijk, Asherson, & Kuntsi, 2010). Furthermore, prenatal and postnatal complications are associated with increased rates of ADHD (Ketzer, Gallois, Martinez, Rohde, & Schmitz, 2012). Recently, different rates of ADHD have been observed regionally. From 2007 to 2009, ADHD prevalence rates in the South and the Midwest were approximately 10%, whereas rates in the West were approximately 5% (Akinbami, Liu, Pastor, & Reuben, 2011). Few theories exist that explain this marked regional variation in rates of ADHD.

One environmental factor that may contribute to the regional disparity in ADHD rates is altitude. Specifically, states at higher altitudes, which are primarily found in the western region of the country, might be more likely to have lower rates of ADHD. This could be due to the effects of mild hypobaric hypoxia, which can increase brain dopamine (DA) levels (Orset et al., 2005; Ray et al., 2011; Trouvin, Prioux-Guyonneau, Cohen, & Jacquot, 1986). Several studies have revealed increased brain DA with hypobaric hypoxia (Orset et al., 2005; Ray et al., 2011; Trouvin et al., 1986). For example, in an animal study by Orset and colleagues (2005), a 1-hr exposure to hypoxia produced by 10% oxygen in nitrogen resulted in an 80% increase in brain DA levels.

DA systems, which typically play a critical role in motor, motivational, and reward processes, are abnormal in individuals with ADHD (Del Campo, Chamberlain, Sahakian, & Robbins, 2011). There have been several studies reporting decreased DA activity in children and adolescents with ADHD (Iversen & Iversen, 2007; Levy, 2004). Treatment of individuals with ADHD typically entails the use of medications that target DA reuptake sites (Rosa-Neto et al., 2005).

DA is a neurotransmitter that requires oxygen for synthesis and proper functioning (Flatmark, 2000). Increases in altitude are directly related to hypobaric hypoxia. Recent altitude studies have shown that individuals may begin to experience behavioral effects of altitude at as little as 2,000 ft (Brenner, Cheng, Clark, & Camargo, 2011). In a study of animals exposed to hypobaric hypoxia for 7 and 14 days at simulated altitudes of 25,000 ft, Ray and colleagues (2011) found over 100% increase in DA.

Individuals living at higher altitudes may experience higher levels of brain DA. We hypothesized that this may ultimately decrease their risk for developing ADHD symptoms and serve as a protective factor. There are no current studies in the literature that examine the effect of altitude of residence on rates of ADHD. The purpose of this study was to investigate whether altitude has an effect on regional variation in rates of ADHD.

Method

ADHD Prevalence Rate Data

Two separate databases were used in the present analyses to examine the mean state altitude of residence on rates of ADHD. State estimates from the 2007 NSCH report from the Centers for Disease Control and Prevention (CDC) were used to extract the percentages of youth aged 4 to 17 diagnosed with ADHD (Child and Adolescent Health Measurement Initiative [CAHMI], 2007). The NSCH inquires about physical and mental health, access to health care, and information about social influences in a child's life such as family and neighborhood. Data were collected from a total of 91,642 interviews and complete ADHD data were obtained for 73,123 children. One child was randomly selected from each household as the focus of the interview. Parents were asked whether a doctor or any other health care provider had diagnosed their child with ADHD or ADD. If the parent reported an ADHD or ADD diagnosis, they were asked to describe the severity (mild, moderate, or severe). Parents were also asked about medication use to treat symptoms of ADHD (CDC, 2009).

In a second analysis, state estimates from the 2010 National Survey of Children With Special Health Care Needs (NS-CSHCN) report from the CDC were used to examine the percentage of youth aged 2 to 17 with ADHD (CAHMI, 2010). The NS-CSHCN evaluates the physical, emotional, and behavioral health of children with special needs, including their access to health care, transition services, and the impact of chronic conditions on the family. In 2010, a total of 372,689 children were screened to identify those with special health care needs. A final number of 40,242 CSHCN interviews were conducted (CDC, 2012). The NSCH and NS-CSHCN utilize random digit-dialed landline telephone surveys and computer-assisted interviewing to conduct the surveys.

Mean State Altitude Data

Mean state altitudes in this study were calculated using Shuttle Radar Topography Mission (SRTM) altitude data. A digital topographical global scale of Earth created in 2000 was used in the data analysis. Mean state altitude allowed accurate calculations due to the 0.1 km spatial resolution of the SRTM dataset. The mean altitude of each state was calculated using zonal statistics within the ArcGIS/ArcInfo 9.3 environment (National Geospatial-Intelligence Agency and National Aeronautics and Space Administration, 2000). Data from 48 states and the District of Columbia were used in the analyses. Alaska and Hawaii were not included in the analyses because digital altitude information was not fully available in the SRTM dataset. State outlines from the National Atlas of the United States (2001) were used to obtain mean state altitudes in feet and the areas in square miles for each included state.

Potential Covariates

To increase confidence in our analyses, we controlled for effects of a number of potential covariates. The included covariates were percentage of youth in the population, percentage of male youth, percentage of births with low birth weight, percentage of overweight/obese youth, population density, percentage uninsured, percentage ever diagnosed with depression or anxiety, ethnicity, and percentage in a two-parent household (Table 1). Covariate variables were either from the 2007 NSCH and 2010 NS-CSHCN datasets or were consistent with datasets and matched the time period of the datasets used in the analyses. The only exception to this is 2007 data for percentage of overweight/obese youth, which was included in both datasets, as this was the most currently available data.

The Current Population Survey (CPS) reports from the U.S. Census Bureau in 2007 and 2010 provided data for the percentage of youth aged 0 to 17 years. The percentage of male youth aged 0 to 17 years was also extracted from 2007 and 2010 CPS reports. The CPS is an annual survey of approximately 78,000 households from all the 50 states and the District of Columbia (U.S. Census Bureau, 2007). The percentage of births with low birth weight was obtained from the National Vital Health Statistics reports in 2007 and 2010 (Martin et al., 2010). Any infant weighing less than 5 lbs 8 oz (2,500 g) was recorded by the National Vital Statistics System in cooperation with the National Center for Health Statistics. The percentage of overweight/obese youth aged 10 to 17 was obtained only for 2007 from the NSCH report (CAHMI, 2007). There were no data available for 2010. Population density from each state was calculated based on the state population projections from the CDC's Wide-ranging Online Data for Epidemiologic Research (WONDER) database for 2007 and 2010 (CDC, 2005) and the area of each state in square miles from the National Atlas of the United States (2001).

Data Analyses

Separate analyses were performed to control for the included covariates. Correlation analyses were conducted between rates of ADHD and the following state-level variables in both datasets: percentage of youth in the population, percentage of male youth, percentage of births with low birth weight, percentage of overweight/obese youth, population density,

percentage uninsured, percentage ever diagnosed with depression or anxiety, ethnicity, and percentage in a two-parent household (Table 2). Variables that did not significantly correlate with rate of ADHD were not included in the models. Altitude and the remaining covariates were loaded into separate models, using rate of ADHD as the dependent variable for both datasets.

The first model included the 2007 NSCH rates of ADHD with altitude; percentage of overweight/obese youth; percentage of births with low birth weight; percentage uninsured; percentage ever diagnosed with depression; percentage ever diagnosed with anxiety; percentage Hispanic; percentage Black, non-Hispanic; percentage other, non-Hispanic; and percentage living in a two-parent household. The second model included the 2010 NS-CSHCN rates of ADHD with altitude; percentage Hispanic; percentage White, non-Hispanic; and percentage living in a two-parent household. Multivariate linear regression analyses were used to investigate the relationship between altitude and rates of ADHD. All analyses were conducted using Statistical Product and Service Solutions (SPSS) version 21. Statistical significance was defined at an alpha level of .05.

Results

NSCH Dataset

Bivariate analysis of the NSCH dataset suggests that mean state altitude ($p < .001$); percentage of overweight/obese youth ($p = .008$); percentage of low birth weight ($p = .002$); percentage uninsured ($p = .008$); percentage ever diagnosed with depression ($p = .045$); percentage ever diagnosed with anxiety ($p = .025$); percentage Hispanic ($p < .001$); percentage Black, non-Hispanic ($p = .026$); percentage other race ($p = .022$); and percentage living in a two-parent household ($p = .016$) were independently, significantly associated with percentage of ADHD prevalence (Table 2). Therefore, the 10 variables were included in a subsequent multiple linear regression model using the Enter method (Table 3).

The regression found that the overall model including the previously mentioned 10 variables was significant, $F(10, 38) = 6.830$, $p < .001$. The total regression model accounts for 64.3% of the variance in ADHD prevalence. Results from the regression model suggest that mean state altitude, percentage of low birth weight, percentage Hispanic, and percentage Black, non-Hispanic were significantly associated with ADHD prevalence. Specifically, for each additional foot in altitude, ADHD prevalence decreased on average by 0.001% when controlling for percentage below birth weight, percentage Hispanic and percentage Black, non-Hispanic, $B = -.001$, $p = .002$, 95% CI = $[-0.001, 0.000]$. On average, for each percentage increase of low birth weight, ADHD prevalence increased by 1.173% when controlling for mean state altitude, percentage Hispanic, and percentage Black, non-Hispanic, $B = 1.173$, $p = .003$, 95% CI = $[0.433, 1.913]$. For each percentage increase in Hispanic population, ADHD prevalence decreases by 0.055% when controlling for mean state altitude, percentage of low birth weight, and percentage of Black, non-Hispanic, $B = -.055$, $p = .044$, 95% CI = $[-0.108, -0.002]$. Last, for each percentage increase in Black, non-Hispanic population, ADHD rates decrease by 0.095% when controlling for mean state altitude, percentage of low birth weight, and percentage Hispanic, $B = -.095$, $p = .050$, 95% CI = $[-0.190, 0.00]$.

NS-CSHCN Dataset

Bivariate analysis of the NS-CSHCN dataset suggests that mean state altitude ($p < .001$); percentage Hispanic ($p < .001$); percentage White, non-Hispanic ($p = .021$); and percentage with two or more adults in the household ($p = .001$) were independently, significantly associated with ADHD prevalence (Table 2). Therefore, the four variables were included in a subsequent multiple linear regression model using the Enter method (Table 3).

The regression found that the overall model including the aforementioned four variables was significant, $F(4, 44) = 12.568$, $p < .001$. The total regression model accounts for 53.3% of the variance in ADHD prevalence. Results from the regression model suggest that mean state altitude and percentage with two or more adults in the household were significantly associated with ADHD prevalence. Specifically, for each 1 ft increase in mean state altitude, the ADHD prevalence decreased by 0.001% when controlling for percentage with two or more adults in the home, $B = -.001$, $p = .017$, 95% CI = $[-0.001, 0.000]$. On average, for each percentage increase in two or more adults in the household, ADHD rates decreased by 0.546% when controlling for mean state altitude, $B = -.546$, $p = .010$, 95% CI = $[-0.958, -0.135]$.

Discussion

Two state-level CDC datasets were analyzed to provide evidence to support the hypothesis that mean state altitude is a significant predictor of ADHD prevalence. Specifically, at higher altitudes, there are lower prevalence rates of ADHD. This study also controlled for potential confounds and is consistent with existing literature in finding a correlation between low birth weight, race/ethnicity, and rates of ADHD. This is the first study to investigate the effects of altitude on the regional variation in rates of ADHD. These findings suggest a need for further investigation into the mechanism in which to consider altitude as a protective factor for ADHD. More speculatively, living at higher altitudes may provide benefits for alleviating symptoms of ADHD.

These findings are related to previous findings from epidemiological research that implicate altitude as a significant risk factor for depressive symptoms (DelMastro et al., 2011) and suicide (Kim et al., 2011). This research also suggests that hypoxia may affect DA levels in the brain. Fiedler and colleagues (2012) found increased cocaine use at higher altitudes. Cocaine and other drug use, such as methamphetamines, have been shown to have an association with depression and mania in bipolar disorder and suicide. Recent studies suggest that the effects of hypoxia may cause an increase of DA that may contribute to these effects (DelMastro et al., 2011; Fiedler et al., 2012; Kim et al., 2011).

The finding that altitude of residence may affect prevalence rates of ADHD should be interpreted with caution. Previous studies of youth have shown risk factors associated with ADHD to include gender, low birth weight, complications of pregnancy, and prenatal exposure to drugs, alcohol, and smoking (Ketzer et al., 2012). Several of these covariates were tested, however, and only low birth weight was found to be a significant predictor of ADHD prevalence rates.

An alternate explanation for geographical differences in rates of ADHD that has recently been reported is solar intensity. Arns, van der Heijden, Arnold, and Kenemans (2013) evaluated the relationship between solar intensity and geographical variation in ADHD rates using national and international data. Results indicated that as solar intensity increased, rates of ADHD decreased after controlling for low birth weight, infant mortality, socioeconomic status, and other relevant factors such as gender and ethnicity. The authors suggested solar intensity may mitigate circadian clock disturbances thought to be associated with ADHD (Arns et al., 2013).

There are limitations that should be considered when interpreting the present data. First, the data was based on state-level data, limiting the altitude variable to mean state-level estimates. However, the results are strengthened by the use of two large independent CDC datasets. It would be important to use sub-state data or data from outside the United States to confirm this effect. In addition, the data used in this study were based on parent report of a child with ADHD or ADD. While questions were based on whether the child had an actual diagnosis of ADHD, there are still limitations associated with the accuracy of parent reporting versus the prevalence of ADHD in the population based upon clinical assessments.

Current treatments for ADHD rely heavily on pharmacological agents. These have short-lasting results and are associated with side effects including growth retardation, agitation, anxiety, aggression, anorexia and insomnia that reduce medication tolerability (Pliszka, 2007). Furthermore, there is mounting national concern regarding possible over-prescription of these drugs, as well as their misuse and diversion. If residence at higher altitudes has benefits for youth with ADHD or serves as a protective factor, this may have implications for treatment.

A treatment that may help alleviate symptoms of ADHD is conducting summer camps for children and adolescents with ADHD at higher altitudes. Providers might also consider the use of hypobaric hypoxia as a novel method of ADHD treatment intervention, but with caution. Altitude devices can create a hypobaric environment, and have been proven safe and effective in training endurance athletes and airplane pilots (Mellor, 2011). They have been shown to induce physiological adaptations that improve physical performance (Bailey & Davies, 1997). Because the use of these devices has not been established in children, further evidence regarding safety and efficacy is necessary before their use in children with ADHD can be recommended.

In conclusion, ADHD is a life-long condition that affects millions of children and adults worldwide, for which there is no cure. Analysis of two large CDC datasets indicates that ADHD prevalence decreases with mean state altitude. The symptoms of ADHD may be ameliorated by increases in brain DA that are known to be associated with hypobaric hypoxia. These observations may have treatment implications for providers and shed light on using natural environmental interventions for ADHD. Future research into the biological mechanism that is affected by altitude for individuals with ADHD is warranted.

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Table 1

Descriptive Statistics for Predictor and Outcome Variables for NSCH and NS-CSHCN.

	NSCH (<i>n</i> = 49)			NS-CSHCN (<i>n</i> = 49)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
% ADHD prevalence	9.95	2.34	5.60–15.60	30.69	4.21	21.50–41.40
Mean state altitude (ft)	1,685.04	1,847.86	58.81–7,192.22	1,685.04	1,847.86	58.81–7,192.22
% population 0–17 years	24.55	1.87	20.21–31.57	24.26	2.16	19.13–31.36
% males 0–17 years	51.08	0.62	49.57–52.78	51.11	0.74	49.24–52.55
% obesity/overweight under 18 years	31.00	4.26	23.10–44.40	31.00	4.26	23.10–44.40
% low birth weight	8.22	1.42	6.10–12.30	11.95	1.71	8.40–17.60
Population density	8,750.64	8,436.23	120.59–25,930.74	8,947.05	8,660.32	122.25–26,849.42
% uninsured	8.38	3.46	2.7–19.4	3.29	1.88	0.5–8.4
% ever diagnosed with depression	4.03	0.99	2.30–6.30	15.94	2.87	10.40–22.40
% ever diagnosed with anxiety	5.06	1.44	2.40–9.80	22.54	3.83	16.20–34.40
% Hispanic	13.02	12.70	1.5–53.9	14.75	12.92	2.2–55.6
% White, non-Hispanic	65.38	17.06	17.5–92.5	64.28	16.85	19.8–92.5
% Black, non-Hispanic	13.28	13.74	0.3–68.2	12.71	12.76	0.4–62.8
% Other, non-Hispanic	8.31	3.90	3.7–21.50	8.27	3.64	3.7–18.8
% two-parent household	75.27	6.61	46.90–88.00	84.62	3.64	74.30–91.70

Note. NSCH = National Survey of Children's Health; NS-CSHCN = National Survey of Children With Special Health Care Needs.

Table 2

ADHD Prevalence Correlation Matrix With Variables of Interest for NSCH and NS-CSHCN.

	NSCH		NS-CSHCN	
	<i>p</i> value	Pearson correlation	<i>p</i> value	Pearson correlation
Mean state altitude	.000 **	−.529	.000 **	−.542
% population 0–17 years	.095	−.241	.122	−.224
% males 0–17 years	.684	.060	.178	−.196
% obesity/overweight under 18 years	.008 *	.373	.169	.200
% low birth weight	.002 *	.438	.080	.253
Population density	.261	.164	.591	.079
% uninsured	.008 *	−.376	.063	−.268
% ever diagnosed with depression	.045 *	.288	.325	.144
% ever diagnosed with anxiety	.025 *	.319	.349	.137
% Hispanic	.000 **	−.538	.000 **	−.604
% White, non-Hispanic	.130	.219	.021 *	.328
% Black, non-Hispanic	.026 *	.318	.092	.244
% Other, non-Hispanic	.022 *	−.326	.117	−.227
% two-parent household	.016 *	−.342	.001 *	−.473

Note. NSCH = National Survey of Children's Health; NS-CSHCN = National Survey of Children with Special Health Care Needs.

* Significant at $p < .05$.

** Significant at $p < .001$.

Table 3

Multivariate Linear Regression Analyses of Predictors for ADHD in the NSCH and NS-CSHCN.

	NSCH				NS-CSHCN			
	<i>B</i>	Lower	Upper	<i>p</i> value	<i>B</i>	Lower	Upper	<i>p</i> value
Mean state altitude	−0.001	−0.001	0.000	.002 *	−0.001	−0.001	0.000	.017 *
% obesity/Overweight under 18 years	−0.082	−0.291	0.127	.433				
% low birth weight	1.173	0.433	1.913	.003 *				
% uninsured	0.172	−0.050	0.394	.125				
% ever diagnosed with depression	0.377	−0.328	1.081	.286				
% ever diagnosed with anxiety	0.241	−0.291	0.773	.365				
% Hispanic	−0.055	−0.108	−0.002	.044 *	−0.019	−0.168	0.130	.800
% Black, non-Hispanic	−0.095	−0.190	0.000	.050 *				
% White, non-Hispanic					0.098	−0.008	0.204	.069
% Other, non-Hispanic	−0.054	−0.192	0.084	.433				
% two-parent household	−0.077	−0.260	0.105	.395	−0.546	−0.958	−0.135	.010 *

Note. Outcome variable: Percentage of ADHD prevalence. NSCH = National Survey of Children's Health; NS-CSHCN = National Survey of Children with Special Health Care Needs. NSCH degrees of freedom: (10, 38); and NS-CSHCN degrees of freedom: (4, 44).

* Significant at $p < .05$.

** Significant at $p < .001$.