Geographic Variation in the Prevalence of Attention-Deficit/Hyperactivity Disorder: The Sunny Perspective

Martijn Arns, Kristiaan B. van der Heijden, L. Eugene Arnold, and J. Leon Kenemans

Background: Attention-deficit/hyperactivity disorder (ADHD) is the most common psychiatric disorder of childhood, with average worldwide prevalence of 5.3%, varying by region.

Methods: We assessed the relationship between the prevalence of ADHD and solar intensity (SI) (kilowatt hours/square meters/day) on the basis of multinational and cross-state studies. Prevalence data for the U.S. were based on self-report of professional diagnoses; prevalence data for the other countries were based on diagnostic assessment. The SI data were obtained from national institutes.

Results: In three datasets (across 49 U.S. states for 2003 and 2007, and across 9 non-U.S. countries) a relationship between SI and the prevalence of ADHD was found, explaining 34%–57% of the variance in ADHD prevalence, with high SI having an apparent preventative effect. Controlling for low birth weight, infant mortality, average income (socioeconomic status), latitude, and other relevant factors did not change these findings. Furthermore, these findings were specific to ADHD, not found for the prevalence of autism spectrum disorders or major depressive disorder.

Conclusions: In this study we found a lower prevalence of ADHD in areas with high SI for both U.S. and non-U.S. data. This association has not been reported before in the literature. The preventative effect of high SI might be related to an improvement of circadian clock disturbances, which have recently been associated with ADHD. These findings likely apply to a substantial subgroup of ADHD patients and have major implications in our understanding of the etiology and possibly prevention of ADHD by medical professionals, schools, parents, and manufacturers of mobile devices.

Attention-deficit/hyperactivity disorder (ADHD) is the most common psychiatric disorder of childhood, with average worldwide prevalence of 5.3% (1). Heritability of ADHD has been reported as 60%–70% (2). Pre- and perinatal factors (preterm birth, low birth weight [LBW]) also play an important role in the etiology of ADHD (3). Additional factors might include global living conditions that could be investigated by inspecting geographic differences in ADHD prevalence.

Previous research reported that 78% of adult unmedicated (4) and one third of medication-naïve pediatric (5) ADHD patients have idiopathic sleep onset insomnia (SOI), accompanied by delayed circadian phase as measured by delayed dim light melatonin onset (6). This finding is supported by melatonin signaling deficiencies (7), clock gene abnormalities (8), and a higher prevalence of "evening types" in adult ADHD (9). Furthermore, a recent meta-analysis incorporating data from 35,936 healthy children reported that sleep duration correlates positively with school performance, executive function, and negatively with internalizing and externalizing behavior problems (10). In addition,

a sleep restriction regime for 3–7 days results in cumulative impairment of attention in healthy adults (11,12) and children (13) and in a tendency for increased θ electroencephalogram (EEG) power (effect size d = .53), (14), which is a measure reported in some ADHD studies, also reflective of fatigue or drowsiness (15,16). These impairments of attention did not normalize after a single night of recovery sleep but only after at least the same number of recovery nights as the number of sleep-restricted nights (11,12). Chronobiological interventions in ADHD patients with insomnia, such as early-morning bright light (17) and long-term melatonin treatment (18), have resulted in an improvement of ADHD symptoms. Additionally, improvement of ADHD symptoms was shown after treatment of other sleep disorders, such as dopamine agonist (19) or iron supplementation (20) for restless legs syndrome and adenotonsillectomy in sleep apnea by (21). Together, these results suggest that, at least in a subgroup of ADHD, the symptoms are exacerbated by sleep problems. In the aforementioned SOI studies, patients were unmedicated (4) or medication-naïve (5). Many well-controlled studies in unmedicated ADHD patients have reported these sleep problems [for review see Yoon et al. (22)]. Thus the increased prevalence of sleep problems in ADHD cannot be explained by effects of stimulant medication. Nevertheless, stimulants often aggravate sleep problems that already existed before stimulant use.

The association of ADHD with circadian disturbances and the powerful impact of bright light on the circadian rhythm, sleep, and daytime function led us to investigate in more detail the relationship between environmental light exposure and ADHD prevalence. This was further encouraged by a graph from the U.S. Centers for Disease Control and Prevention (CDC) (23) depicting differences in ADHD prevalence for the U.S. (Figure 1, left) and solar intensity (SI) maps for the U.S., available from the National Renewable Energy Laboratory (NREL) (Figure 1, right). We noted that the U.S. states with maximum SI (Arizona, New Mexico,

From the Department of Experimental Psychology (MA, JLK), Utrecht University, Utrecht; Research Institute Brainclinics (MA), Nijmegen; Leiden Institute for Brain and Cognition (KBvdH), Department of Clinical Child and Adolescent Studies, Leiden University, Leiden, the Netherlands; and Ohio State University (LEA), Columbus, Ohio.

Address correspondence to Martijn Arns, Ph.D., Department of Experimental Psychology, Research Institute Brainclinics, Bijleveldsingel 34, Nijmegen 6524 AD, The Netherlands; E-mail: martijn@brainclinics.com.
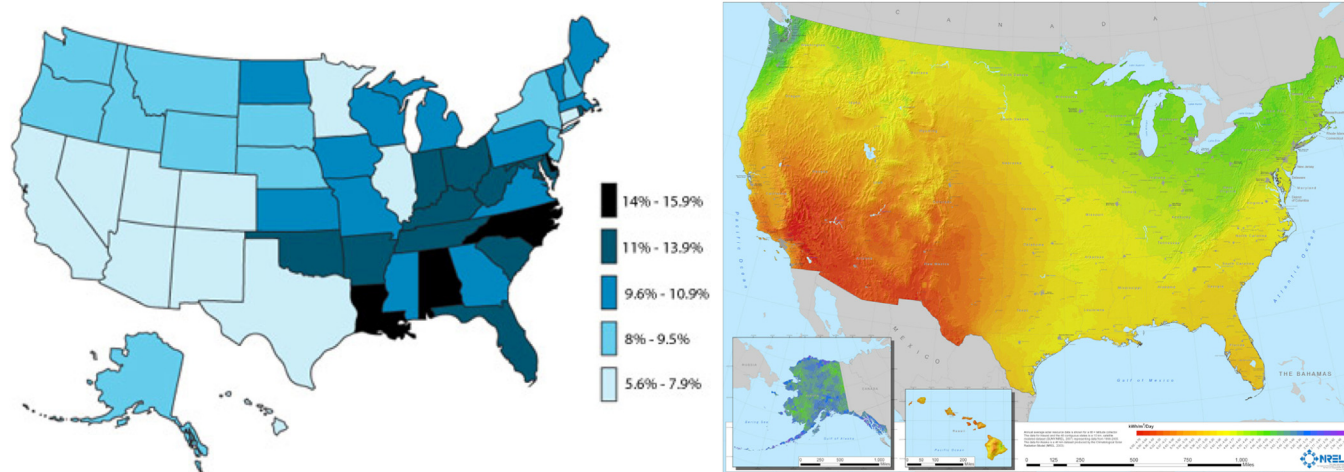
Figure 1. Comparison between the prevalence of attention-deficit/hyperactivity disorder (ADHD) and solar intensity (SI) in the U.S. This figure demonstrates on the left map the prevalence rate of ADHD among different U.S. states (U.S. Centers for Disease Control and Prevention, 2010; http://www.cdc.gov/ncbddd/adhd/prevalence.html). The figure on the right depicts the horizontal irradiation or SI (SI in kilowatt hours/square meters/day) across the U.S. as reported by the National Renewable Energy Laboratory (map created by the National Renewable Energy Laboratory for the Department of Energy). Note the similarity between the areas with highest SI (depicted in red) and those with the lowest prevalence of ADHD (palest blue).

Nevada, California, Utah, and Colorado) also had the lowest prevalence of ADHD. Therefore, in this study we sought to systematically investigate the relationship between the prevalence of ADHD and SI as a measure of visible and nonimage forming light (expressed in kilowatt hours/square meters/day). We hypothesized that high SI is associated with lower rates of ADHD by its overwhelming phase-advancing effect on the circadian clock.

Methods and Materials

ADHD Prevalence Estimates

Searches were performed to uncover statistics about the prevalence (PREV) of ADHD around the world or across states employing standardized procedures, to facilitate valid comparisons of PREV estimates.

Solar Intensity

Horizontal irradiation (radiation reaching the surface of the earth on a horizontal plane, expressed in kilowatt hours/square meters/day; SI data: SI) were obtained from national and international agencies: U.S. National Renewable Energy Laboratory (NREL[A]) for the U.S. (NREL: P. Gray-Hann, personal communication, August 24, 2012), global horizontal irradiation, State University of New York (Mexico), global horizontal irradiation, National Institute for Spatial Research (Colombia), and the European Institute for Energy and Transport (IET[B]) for Europe and other countries.

The radiation model used by NREL was developed by Perez *et al.* (24) and "…uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the mount of aerosols in the atmosphere to calculate the hourly total insolation…falling on a horizontal surface…" (25). Similar methods were used by IET; for more details see Šúri *et al.* (26).

Statistics

The relationship between PREV and SI was investigated by curve estimation. For nonlinear relationships, an appropriate transformation (log or square root) was applied to obtain the most significant linear trend. A correlation was calculated between PREV and SI as well as with other potential confounding variables, such as latitude, altitude, and (for the U.S.) average income (socioeconomic status), LBW, and infant mortality (IM)/state (CDC data) and other factors reported by the ADHD PREV studies obtained (Pearson correlation, two-tailed). Those factors that were found significantly correlated with PREV were introduced as control variables in partial correlation analyses between PREV and SI (two-tailed). Finally, to investigate specificity for ADHD, we conducted the same analyses for autism spectrum disorders (ASD) and major depressive disorder (MDD) in the U.S. data that were also obtained from the CDC.

Results

Two data sources were identified that employed identical methods to estimate the prevalence of ADHD. These sources were the PREV estimates in children from the CDC/U.S. state (23) and the PREV estimates for adults across several countries (27).

ADHD Prevalence Across U.S. States: CDC

The CDC data were collected in 2003 and 2007 and were part of the National Survey of Children's Health in children under 18 years of age. This survey was a national, cross-sectional, random-digit-dialed landline telephone survey, where one child was selected randomly from each household to be the focus of the parent or guardian interview (response rates: 68.8% in 2003 and 46.7% in 2007) (23). Parents were asked whether or not a doctor or other healthcare provider had ever told them that their child had "attention-deficit disorder or attention-deficit/hyperactivity disorder, that is, ADD or ADHD" (23). Higher rates of ADHD were found among boys, multiracial children, and children covered by Medicaid.

Figure 2 demonstrates the relationship between SI and PREV for 2003 and 2007. As can be seen from Figure 2, this relationship does not seem linear, which was confirmed by curve estimation (all statistics are represented for 2003 │ 2007, respectively). The best fit was obtained by a sigmoidal dose-response relation