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A review of prevalence studies of Autism Spectrum Disorder by latitude and solar irradiance impact

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A B S T R A C T

Autism Spectrum Disorder (ASD) is a lifelong disability with no known cause or cure. Among the suggested etiologies, is Cannell's hypothesis of a deficiency in Vitamin D the main natural source of which is Solar Ultraviolet-B (UVB) radiation. The aim in this paper is to build on this hypothesis and explore the relationship of solar irradiance of which UVB is a component, by latitude with the prevalence rates of ASD. Twenty-five reports published between 2011 and 2016 using comparable diagnostic criteria were reviewed. The results suggest a tendency for the prevalence rates of ASD to be lowest in countries near the equator and for this rate to increase as the latitude increases. These findings provide some support not just for the Vitamin D hypothesis, but also for a new proposition that along with UVB radiation, the entire solar radiation spectrum which reaches the earth, may play a role in ASD. While these results are both novel and encouraging in terms of the potential efficacy of exposure to natural sunlight, further research is warranted before results can be considered definitive, and before the implications of the findings can be implemented clinically.

Introduction

Autism Spectrum Disorder (ASD) is an umbrella term for multiple neurodevelopmental conditions characterized by repetitive or stereotyped behaviors and pervasive deficits in social communications and interactions [1]. ASD is considered a lifelong disability which has an impact on both the individual and the family [2,3], as well as being a cost to society in general [2,4]. Among these costs are additional health care, disability support in school and, in some instances, the loss of a productive working life and the provision of social security. In addition, ASD is associated with several comorbidities [5,6] such as Attention-Deficit/Hyperactivity Disorder [7–10], Obsessive Compulsive Disorder [7,8], anxiety disorders [11–15], sensory over-responsivity [13,16–19], sleep disorders [20–22], and gastrointestinal problems [13,20,23,24].

The prevalence of ASD, or at least reports thereof, have increased substantially from 1 in 500 in 1995, 1 in 250 in 2001 [25], to 1 in 68 in 2010 in the USA in children less than 8 years [26]. However, it is possible that rather than an actual increase in the rate of ASD, these statistics reflect higher prevalence associated with expanded definitions of ASD, increased public awareness and help-seeking. Further changes in the prevalence rates for ASD may also be a product of social de-stigmatization associated with ASD [27].

Despite the efforts of scientists who have investigated a myriad of environmental and genetic factors including air pollution [28–32]; environmental toxins such as mercury, nickel, selenium, lead, cadmium, aluminum, vinyl chloride and trichloroethylene [33–37]; genetic heritability [38–40]; hormonal imbalances such as oxytocin [41], vasopressin [42], and more recently Vitamin D deficiency [43,44] the etiology of ASD remains uncertain.

Following Cannell's proposal [43,44] that Vitamin D deficiency could be a risk factor for ASD several researchers have found low Vitamin D levels in patients with ASD [45,46], their siblings [47] and also maternal deficiencies [4,48,49]. Laboratory research has explored the genes regulated by Vitamin D [50,51]. Overall, these results have pointed towards an association between Vitamin D deficiency and autism-related traits [44,52]. Further support for Cannell's hypothesis comes from reports that some level of improvement in autistic symptoms has been achieved via the administration of Vitamin D supplements [53–55]. Despite this tentative support for an association between Vitamin D and ASD, no conclusive evidence of this relationship

Abbreviations: ADI-R, Autism Diagnostic Interview-Revised; ADOS, Autism Diagnostic Observation Schedule; ASSQ, Autism Spectrum Screening Questionnaire; ASQ, Autism Screening Questionnaires; BSA, Body Surface Area; CAST, Mandarin Childhood Autism Spectrum Test; ICD-10, International Classification of Diseases, 10th edition; ISAA, Indian Scale for Assessment of Autism; M-CHAT, Modified Checklist for Autism in Toddlers; M-CHAT/ES, Spanish version of the Modified Checklist for Autism in Toddlers; VBAS, Vineland Adaptive Behaviour Scale

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has emerged.

In line with the research into Vitamin D deficiency, recent research has addressed a link between solar irradiance and ASD [56–58]. Solar irradiance is the measure of the sun's electromagnetic spectrum over all wavelengths per unit area, usually described in watts per meter^2 (W/m^2) units [59]. The earth's atmosphere filters the sun's electromagnetic radiations leaving Ultraviolet (UV), Visible, and Infrared radiations as the main biogenically relevant components [60] to reach the earth's surface. UV is further classified into UVA, UVB and UVC [59,61]. UVA reaches the earth's surface throughout the year, UVB reaches the surface only when the sun is high in the sky, while UVC is completely blocked by the earth's atmosphere [59].

When people are exposed to UVB radiation, 7-dehydrocholesterol present in the skin is converted to pre-Vitamin D_3 and provides the main source of natural Vitamin D to the body [56] Some research has reported a correlation between low solar UVB and high ASD prevalence [56–58] with this higher ASD prevalence attributed to lower levels of sunlight based Vitamin D production. These studies were, however, limited in scope. Firstly, they focused only on the UVB based Vitamin D part of the electromagnetic spectrum; secondly, there was a noticeable omission of ASD prevalence rates from countries near the equator, which receive the highest levels of solar irradiance.

The aim of current study was to build on these investigations by examining the incidence of ASD across the globe by latitude and its relationship with solar irradiance which decreases as distance from the equator increases. This study, for the first time, proposes a link between ASD and solar irradiance across all electromagnetic wavelengths. This hypothesis will be investigated by comparing the results of published epidemiological studies from different countries and plotting their ASD prevalence rates by the latitude of the data sources.

Method

Published data were used for this study therefore approval from the University's Ethics Committee was not required.

Inclusion Criteria. Reports on the prevalence of ASD in children and adolescents were sought via searches of the major databases (PubMed, Google Scholar, ScienceDirect, Medline, Psychinfo) and a non-content database (Web of Knowledge). Search terms of "Autism" and "incidence/prevalence/epidemiology" were used. Subsequent searches included the name of countries/regions where gaps in geographical areas were identified. In order to minimize the impact of any unknown factors and diversity in earlier assessments, only the latest reports based on comparable diagnostic criteria were reviewed for this study.

Each study revealed by the search was examined individually and included in the analysis if it met the following criteria: 1) Original publication between 2011 and 2016; 2) reported on samples less than 18 years of age; 3) used recognized diagnostic criteria (e.g. DSM-IV or ICD-10) or nationally modified diagnostic criteria for determining the prevalence of ASD; 4) was representative of a reasonably defined geographic area, that is, inside 10 degrees of latitude (for determination of latitude and solar irradiance levels); and 5) represents the largest sample size.

In sum 25 studies met all four inclusion criteria. A further study from Australia that did not meet the inclusion criteria due to its wide geographical coverage exceeding 10 degrees of latitude will be discussed separately.

Results and discussion

The locations of the 25 studies reviewed are identified on the map in Fig. 1. Although prevalence rates from some regions that is, Russia and southern Africa, are not represented, with respect to street level solar irradiance at latitudes, the entire globe is represented (Fig. 1). An overview of the studies is listed in Table 1 including sample age, ASD prevalence and the diagnostic criteria used. The prevalence rates plotted by their respective latitude and solar irradiance level [62] are shown in Fig. 2.

Cannell's hypothesis [43], wherein he linked low levels of Vitamin D with ASD, was explored with respect to solar irradiation as a natural source of Vitamin D, and the results provide partial support for the exploration of this relationship. In general, the prevalence of ASD is shown to increase with increasing latitude while decreasing with increasing altitude. Fluctuations in both factors may be attributable to differences in elevation, pollution levels, annual solar irradiance, individual Body Surface Area (BSA) exposure, use of sunscreen protections, and skin pigmentation.

Overall, there is a tendency for ASD prevalence rates to increase and solar irradiance to decrease as the distance from the equator increases is shown in Fig. 2. There are peaks in prevalence rates which diverge from the line of best fit with Japan, South Korea and China having considerably higher prevalence rates of ASD while France has a lower rate (Table 1).

A notable finding is the increase in ASD prevalence above 25° latitude which maybe attributable to the decrease in solar irradiance which, until that point shows only a minor decrease. The other main finding is the continual increase of ASD prevalence above 33° latitude. During the winter months for those living above approximately 33° latitude very little if any Vitamin D_3 can be produced in the skin from sun exposure [87] due to an increase in blockage of UVB by the atmosphere. Support for this premise can be seen in reports from Boston, USA (42 °N), Edmonton, Canada (52 °N), and Bergen, Norway (61 °N) where residents are reported to be unable to produce sufficient quantities of Vitamin D in their skin for four, five, and six months of the year, respectively [87,88]. Similar findings have been reported elsewhere [89–91].

In the reports reviewed, Oman [69] has the lowest prevalence of ASD followed by Taif, Saudi Arabia [67], Costa Rica [64], Himachal Pradesh, India [73], Quito, Ecuador [63], Leon, Mexico [66], Atibaia, Brazil [68], Taiwan [70] and Shoranur, India [65] in that order. All of these regions lie below 25° latitude except for Himachal Pradesh (India) and the prevalence rates were all less than 0.31%.

The Oman study was based on the nation-wide coverage of participants diagnosed at one center. From 798,913 children aged 0–14 years only 113 cases of ASD were found based on DSM-IV-TR criteria. In addition to being close to the equator, Oman has a hot desert climate. Both of these may play a role in higher exposure to solar irradiance. The study from Saudi Arabia shows a prevalence rate of 0.035% from a sample population of 22,950 7–12 year-old students in the primary schools of Taif district. The Costa Rican study was based also on a nation-wide sample [92,93] where, in the 1–5 year-old population, the prevalence of ASD was 118 children from a sample size of 290,375. The Himachal Pradesh study was carried out at 32° latitude in the Himalayan Mountains in India and the only study beyond 25° latitude to have a prevalence rate of less than 0.3%. The reported low prevalence rate of 0.09% may be attributed to the elevation at which this study was carried out as at high elevation, solar irradiance (including UVB) is higher than at sea-level due to reduced travel-distance through the earth's atmosphere. Lower ASD prevalence at higher elevation further supports the argument for its association with solar irradiance.

In the Indian study [73] 11,000 children aged 1–10 years in the identified region were surveyed by trained investigators using a Hindi language version of the Indian Scale for Assessment of Autism (ISAA) based on the Childhood Autism Rating Scale (CARS). The authors of the Ecuadorian study [63] reported a prevalence rate of 0.11% in school going children of 5–15 years. The Leon (Mexico) study also found a low prevalence of 0.11% [66]. This Mexican study has reported on ASD rates in mainstream school going children and special education school children. The former prevalence rate was included here as a better representation of the overall population sample. Paula et al. [68] looked