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Review Article

Endocrine Disruptors and Attention Deficit Hyperactivity Disorder: A Systematic Review

Marta Lopez-Garcia,[a] Manuel Martinez-Bebia,[a] Alejandro Lopez-Moro,[b,*] Nuria Gimenez-Blasi,[c] José Antonio Latorre,[a] and Miguel Mariscal-Arcas[b,d]

[a] *Department of Food Technology, Nutrition and Food Science, University of Murcia, Murcia, Spain*
[b] *Department of Nutrition and Food Science, Health Science and Nutrition Research, School of Pharmacy, University of Granada, Granada, Spain*
[c] *Department of Health Sciences, Catholic University of Avila, Avila, Spain*
[d] *Instituto de Investigación Biosanitaria de Granada, Granada, Spain*

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The increasing prevalence of attention deficit hyperactivity disorder (ADHD) in children has prompted more research on both genetic and environmental risk factors, including endocrine-disrupting chemicals (EDCs) such as bisphenol A (BPA) and polychlorinated biphenyls (PCBs). This review focuses on studies published between 2013 and December 2023 that explore the potential impact of BPA and PCBs on ADHD. The review draws from databases such as WOS, PubMed, and Scopus. BPA, a chemical commonly used in plastics and resins, has raised concerns due to its potential neurodevelopmental effects, particularly when exposure occurs prenatally. Multiple studies have suggested an association between prenatal BPA exposure and an increased risk of ADHD in offspring, though more research is needed. Similarly, PCBs, which are persistent environmental pollutants primarily found in contaminated food sources, have been linked to cognitive and behavioral issues, including attention deficits and hyperactivity. Both BPA and PCBs have been shown to disrupt neurodevelopment, underscoring the importance of regulating these chemicals to safeguard children's health. While these findings highlight a potential risk, further studies are required to clarify the underlying mechanisms and the precise role these EDCs play in the development of ADHD and other neurobehavioral disorders.

Keywords: Attention deficit hyperactivity disorder, ADHD, BPA, EDCs, PCB.

Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by symptoms of hyperactivity, impulsivity, and inattention (1). It is estimated that 5–10 % of the pediatric population is affected by this disorder, making it one of the most common psychiatric conditions in childhood (2). Individuals with ADHD often have difficulties in maintaining attention, exhibit reduced reflective thinking, and experience behavioral and social interaction problems. These difficulties are related to challenges following so-called rule-governed behaviors (RGB) and performing sustained attention tasks (3). Diagnosis is based on information collected through clinical history and interviews with the child, their parents, and teachers or caregivers.

There has been a significant increase in the prevalence of ADHD over the past 20 years (1997–2016), rising from 6.1 to 10.2 % among children and adolescents in the United States. This trend may reflect a combination of factors, including increased awareness, improved access to diagnostic services, and changes in diagnostic criteria, as well as potential environmental influences (4). While this

Address reprint requests to: Alejandro López-Moro, Department of Nutrition and Food Science, University of Granada, Campus of Cartuja s/n. 18071, (Granada), Spain; E-mail: alexlopez@ugr.es

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growth highlights the need for further investigation, it is essential to interpret these findings with caution, considering the complexity of ADHD diagnosis and the influence of social and cultural factors.

Environmental and genetic factors are believed to significantly contribute to the development of ADHD, though the exact mechanisms remain under study. Exposure to substances during pregnancy, environmental pollutants, and genetic predispositions are all associated with an increased risk of ADHD (4). Family studies provide strong evidence for a genetic component, showing prevalence rates of 20–50 % in first-degree relatives and up to 76 % concordance in twin studies (5). However, while these factors may increase susceptibility, they do not necessarily indicate direct causation; instead, they likely modulate the course and expression of the disorder (6). This distinction is important to avoid overestimating the role of any single factor.

Another exposure to consider is to heavy metals and chemicals. Elevated levels of lead and/or manganese in the bloodstream have been associated with an increased risk of developing ADHD (6). Children whose mothers had greater prenatal exposure to polychlorinated biphenyls (PCBs) and p,p'-dichlorodiphenyldichloroethylene had a 26–93 % higher risk of exhibiting ADHD-like symptoms (7). High levels of organophosphate pesticides in the body have also been associated with an increased risk of developing ADHD, because these substances can penetrate the placenta and affect the neurodevelopment of the offspring and increase their susceptibility to ADHD and other cognitive or behavioral disorders (6).

Endocrine Disruptors

The World Health Organization (WHO) defines endocrine disruptors as "an exogenous substance or mixture that alters the function of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or populations" (8). These are essentially substances that contaminate the environment and disrupt the hormonal balance of organisms when absorbed. Adverse effects include metabolic, cardiovascular and neurodevelopmental disorders, as well as thyroid dysfunction, reproductive issues, and cancer, among others (9).

Endocrine disruptors can be persistent, meaning they accumulate in the body and can act over long periods, or non-persistent, meaning they are easily eliminated, and act over short periods of time (10).

Depending on their concentration, biodegradability, bioaccumulation, and location, endocrine disruptors can act in various ways. These effects also vary according to the timing of exposure, as well as the hormonal balance, age, and sex, and other circumstances. Another characteristic factor is the accumulation of these compounds in maternal body fat, from where, they are transmitted to future offspring during gestation and breastfeeding. Despite the wide variety of entry routes for endocrine disruptors, humans are mainly exposed through the digestive tract via contaminated drinking water, can linings and food packaging. Other exposure routes include inhalation through the air, and consumption of food itself, particularly dairy products, fish, seafood, meats, and oils. This is due to the lipophilic nature of many endocrine disruptors, which facilitates their fat accumulation (9,10).

The impact of these substances depends on the exposure period, with critical periods being the most important for determining their nature, severity, and progression. One decisive factor is the age at which exposure occurs. If a woman is pregnant, the gestational week is also important because these effects occur more frequently in progeny and future generations. Sometimes, manifestations may not be evident until adulthood (9). One effect that endocrine disruptors can produce is on neurodevelopment, hindering learning and concentration and causing problems in the development of the central nervous system (10).

Certain endocrine disruptors are particularly associated with neurodevelopmental effects. These include organochlorines (e.g., PCBs, dioxins, furans), brominated flame retardants, pesticides, bisphenol A (BPA), perfluorinated compounds, and heavy metals (e.g., lead, mercury and arsenic) (11).

According to a classification of endocrine disruptors, those that affect neurological development include organochlorines (PCBs, dioxins, and furans), brominated flame retardants (BFRs), perchlorate, pesticides, BPA, perfluorinated substances (PFOA and PFOS), phthalates, ultraviolet filters (4MBC, OMC, PB2BP3), and heavy metals (lead, mercury, and arsenic) (11). Their classification is based on their ability to bioaccumulate, disrupt hormone signaling, and act during critical developmental periods. While these compounds have been linked to an increased risk of neurodevelopmental disorders, including ADHD, not all studies have found consistent results. Differences in study design, population exposure levels, and diagnostic methods may contribute to variability in outcomes. This underscores the need for standardized research protocols to draw more definitive conclusions.

Endocrine disruptors may interfere with neurodevelopmental processes by disrupting hormone signaling. According to the WHO, these substances can mimic hormones, block receptor activity, alter hormone synthesis or metabolism, or modify receptor levels, leading to adverse effects (12). Neurodevelopmental impacts include potential impairments in learning, concentration, and central nervous system development, particularly when exposure occurs during critical windows such as gestation or early childhood (10). However, not everyone exposed to these disruptors will experience the same effects, because factors such as dose, timing, and genetic susceptibility play significant roles. Further research is needed to clarify these mechanisms and their relevance to ADHD.

The aim of this systematic review is to explore whether endocrine disruptors have contributed to the increased incidence of children diagnosed with ADHD in recent years, or if they exacerbate symptoms in individuals already diagnosed. Our main objective is to examine how endocrine disruptors affecting neurodevelopment impact ADHD incidence. To this end, we will focus on BPA and PCBs due to their relevance in nutrition and diet, as well as their potential impact on human health. We will investigate whether exposure to BPA influences the onset of ADHD and its significance during pregnancy and early childhood. Furthermore, we will analyze whether exposure to PCBs affect ADHD symptomatology.

Material and Methods

The structure of this review has followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (13), and it has been appropriately registered on Figshare (DOI:10.6084/m9.figshare.25721478).

Data Extraction

The literature search was conducted between September and December 2023. Data were obtained from direct consultation and online access to the following health sciences bibliographic databases: MEDLINE (via PubMed), Scopus and Web of Science.

Information Processing

To systematize and facilitate understanding of the results, the articles were classified according to study variables. The following data were considered: first author, year of publication, quality index, characteristics, type of study, objectives, and results,

All data were obtained from the articles accepted for review. In accordance with the Biomedical Research Law 14/2007, ethical committee approval was not required since secondary data were used.

The Thesaurus of Health Sciences Descriptors (DeCS), developed by the Latin American and Caribbean Center for Medical Sciences Information (BIREME) and its equivalence with the Medical Subject Headings (MeSH) established by the United States of America National Library of Medicine, were consulted to define the search terms.

From the study of the hierarchical structure of both the Thesaurus and their indexing cards, the following equations were determined to be appropriate:

Attention Deficit Disorder with Hyperactivity (ADHD) (DeCS term): A behavioral disorder with childhood origins and whose essential features are developmentally inappropriate inattention, impulsivity and hyperactivity. Although most individuals present with symptoms of both inattention and hyperactivity-impulsivity, one pattern may predominate. The disorder is more prevalent in males than in females. It appears in childhood and symptoms often subside in late adolescence, though some experience symptoms in middle adulthood. (From DSM-V). (((((Attention Deficit Disorder with Hyperactivity [MeSH Terms]) OR (adhd[MeSH Terms])) OR (Attention Deficit Disorder with Hyperactivity[Title/Abstract])) OR (Déficit de atención e hiperactividad [MeSH Terms])) OR (Déficit de atención e hiperactividad [Title/Abstract])) OR (adhd [Title/Abstract]).

First, general information on endocrine disruptors and their influence on neurodevelopment was sought. Subsequently, a more specific search was made on what kind of endocrine disruptors affect ADHD as:

Bifenilos policlorados (DeCS term): Industrial products consisting of a mixture of chlorinated biphenyl isomers and congeners. These compounds are highly lipophilic and tend to accumulate in the fat stores of animals. Many of these substances are considered toxic and potential environmental pollutants.

"Bisphenol A," "Bisfenol A," "BPA," "PCB." There are no DeCS terms or MeSH equivalents. ((((((((((Bifenilos Policlorados[MeSH Terms]) OR (Bifenilos Policlorados[Title/Abstract])) OR (Polychlorinated biphenyls [MeSH Terms])) OR (Polychlorinated biphenyls[Title/Abstract])) OR ((Bisphenol A[Title/Abstract]))) OR (Bisfenol A[Title/Abstract])) OR (BPA[Title/Abstract])) OR (PCB[Title/Abstract]).

The final search equation was developed for use in the MEDLINE database, via PubMed, through the Boolean union (and OR) using the filters full text and 10 years:

((((((Attention Deficit Disorder with Hyperactivity [MeSH Terms]) OR (adhd [MeSH Terms])) OR (Attention Deficit Disorder with Hyperactivity[Title/Abstract])) OR (Déficit de atención e hiperactividad [MeSH Terms])) OR (Deficit de atención e hiperactividad [Title/Abstract])) OR (adhd [Title/Abstract])) AND ((((((((((Bifenilos policlorados [MeSH Terms]) OR (Bifenilos policlorados [Title/Abstract])) OR (Polychlorinated biphenyls[MeSH Terms])) OR (Polychlorinated biphenyls[Title/Abstract]))) OR (Bisphenol A [Title/Abstract]))) OR (Bisfenol A [Title/Abstract])) OR (BPA [Title/Abstract])) OR (PCB [Title/Abstract])).

The following inclusion and exclusion criteria were applied to the literature search to obtain more specific information:

- Inclusion criteria: Articles published in the last 10 years, open-access articles, articles written in English or Spanish, and research conducted on humans.
- Exclusion criteria: Studies conducted on animals, articles not available in full text, and articles not written in English or Spanish.

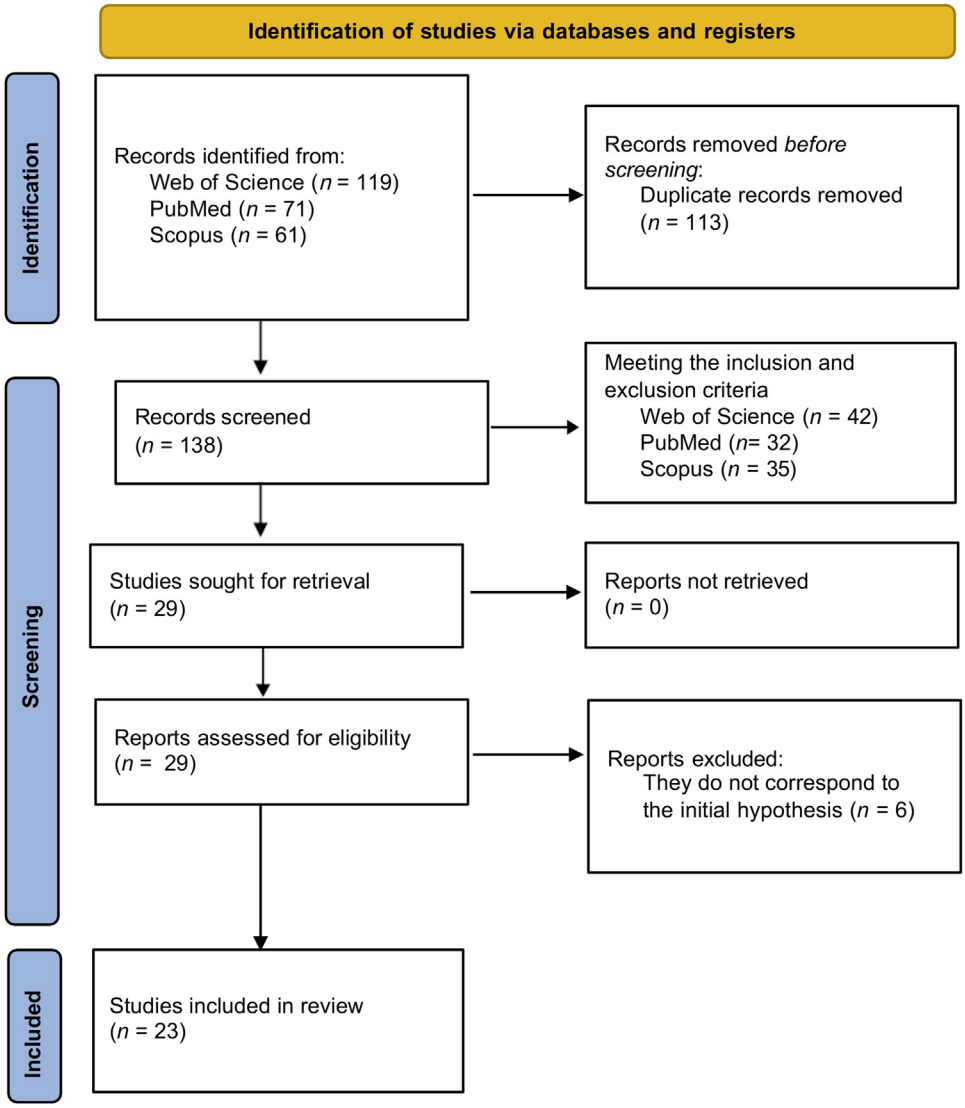

Figure 1. Flowchart for study identification and selection.

Results

By entering different search strings, a total of 251 results were obtained. However, after excluding duplicates and those eliminated upon reading the abstract and determining they did not align with the interests of this review, the total number of articles was reduced to 118. After applying filters for the last 10 years and marking the availability of full and free text, the total number of articles was reduced to 29. Six articles were also excluded because they did not align with the proposed hypothesis. The total number of articles included in the review is 23. The search process is represented in Figure 1.

The results of studies on the association between exposure to bisphenols (BPA, BPF, and BPS) and ADHD are varied, as shown in Table 1. According to findings by Kim et al., the levels of BPA, BPF, and BPS are associated with ADHD symptoms at six years old. The higher the level of BPA, the stronger the relationship. The sample consisted of 619 participants: 325 boys and 294 girls. At age four, BPA levels in urine were seen to be higher (3.29 μg/g creatinine). Furthermore, as the children grew older, levels decreased (2.83 μg/g at age five, 2.67 μg/g at age six, 2.25 μg/g at age seven, and 1.96 μg/g at age eight). On the other hand, levels of BPF and BPS increased with age. By age eight, the geometric mean was 0.40, and 0.16 μg/g for BPF and BPS, respectively. Though safety thresholds were not specified, higher levels of BPA, BPF, and BPS were associated with ADHD symptoms. Furthermore, the association was stronger for girls than for boys. However, ADHD symptoms were significantly higher when BPA levels were greater than 3.0 μg/g (14). Rochester JR and Bolden concluded that early BPA exposure was associated

Table 1. Description of studies related to the association between exposure to bisphenols (BPA, BPF, and BPS) and ADHD.

Author	Quality index	Characteristics	Type of study	Objectives	Outcomes
Kim et al. (14)	FI: 11,8 Q1 (17/274)	Number of participants: 619 mother-child pairs. Target group: mothers during gestation and their children aged 4–8 years. Neurological assessment: ADHD. Rating Scale IV (ARS). Enrollment from 2008 to 2010. BPA concentration: maternal urine and blood sample between 14 and 27 weeks of gestation.	Prospective cohorts	To investigate the association between childhood exposure to bisphenols (BPA, BPF and BPS) and ADHD symptoms at 4, 6 and 8 years of age.	BPA, BPF and BPS are related to ADHD symptoms at age 6, and the association was stronger among those with higher BPA levels at age 6.
Rochester et al. (15)	FI: 7,8 Q1 (8/251)	Number of articles: 32, of which only 3 were conducted in humans. The search encompassed all literature up to January 2017.	Systematic review and meta-analysis	Determine the relationship between early BPA exposure and hyperactivity.	Early BPA exposure was associated with hyperactivity in both boys and girls.
Hansen et al. (16)	FI: 7,1 Q1 (30/210)	Number of participants: 658 mother-child pairs with 2 year-old children and 427 5 year olds. Target group: children aged 2–5 years. Neurological assessment: Child Behavior Checklist (CBCL 1½–5) questionnaire. BPA concentration: Urine sample at the 28th week of gestation. Enrollment period: 2010–2012.	Cohorts	To evaluate the association between intrauterine exposure to BPA and ADHD symptoms in Danish children aged 2 and 5 years.	No associations were found between maternal BPA exposure and ADHD at age 5.
Jensen et al. (17)	FI: 5,7 Q1 (15/193)	Number of Participants: 658 mother-child pairs. Target Group: Children aged 1½–5 years. Neurological Assessment: Child Behavior Checklist (CBCL). BPA Concentration: Maternal urine sample in the third trimester. Enrollment Period: 2010–2012.	Prospective cohorts	Assessing if maternal urine BPA concentration during pregnancy is associated with ADHD symptoms in children aged 18 to 26 months.	There is no evidence of an association between prenatal BPA exposure and ADHD behavior.
Li et al. (18)	FI: 5,7 Q1 (25/251)	Number of participants: 215 children with ADHD and 253 control children. Target group: Children aged 6–12 years Neurological assessment: DSM-5 and CBCL or CPSQ. Enrollment from 2014 to 2017. BPA concentration: Urine simples	Cases and controls	Investigate if childhood exposure to BPA is associated with the onset of ADHD.	There are significant differences in BPA levels and the increased risk of ADHD. It is observed that BPA exposure in boys may have a greater impact than in girls.
Huang et al. (19)	FI: 5,1 Q2 (45/146)	Number of participants: 1782 mother-child pairs. Target group: Children aged 3 and 4 years. Neurological assessment: Behavior Rating Inventory of Executive Function-Preschool (BRIEF-P), Strengths and Difficulties Questionnaire (SDQ), Conners Abbreviated Symptom Questionnaire (C-ASQ), Enrollment period: 2008 to 2010. BPA concentration: Maternal blood sample during gestation.	Prospective cohorts	Examine the associations between prenatal serum concentrations of BPA and behavior and cognitive function in preschool-aged children.	High prenatal BPA exposure was significantly associated with significantly higher ADHD among 3 year-old boys, but the association was null among 4 year-old boys.
Minatoya and Kishi (20)	FI: 4,6 Q2 (71/210)	Number of articles: 24 on BPA. A search was conducted between 2019 and 2020, incorporating articles from 5 years ago.	Narrative review	Study prenatal and postnatal exposures to bisphenol A and phthalates and their association with children's neurological development and behavioral outcomes.	Symptoms of ADHD, especially among children, consistently suggested an association with prenatal and concurrent exposure to bisphenol A.

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Table 1 (*continued*)

Author	Quality index	Characteristics	Type of study	Objectives	Outcomes
Moore, et al. (21)	FI: 4,6 Q2 (71/210)	Number of articles: 8 on BPA. A bibliographic search was conducted on PubMed in 2020.	Scope review	Summarize the known associations between ADHD and exposure to priority chemicals from the European Human Biomonitoring Initiative.	The compiled evidence indicates a moderate to high level of association between BPA and ADHD.
Tsai et al. (22)	FI: 4,1 Q2 (30/92)	Number of participants: 98 boys and 32 girls with ADHD, in addition to 42 boys and 26 girls as controls. Target group: Children aged 6–12 years. Neurological assessment: WISC-IV questionnaire and SNAP-IV. BPA concentration: Urine samples from the children.	Transversal	Examine whether endocrine disruptors, including bisphenol A, affect gonadal hormones and susceptibility to ADHD.	The levels of BPA were higher in children with ADHD compared to the control group, although the difference was not statistically significant.
Harley et al. (23)	FI: 3,9 Q1 (15/162)	Number of participants: 292 mother-child pairs. Target group: Children aged 7–9 years. Neurological evaluation: BASC-2 survey and Conners' ADHD/DSM-IV scales. At age 9, ADHD was also assessed using the Conners' Continuous Performance Test (CPT). Enrollment period: 1999 to 2000. BPA concentration: Urine sample from pregnant women less than 20 weeks gestation.	Longitudinal cohorts	To examine the association between maternal urinary BPA concentrations during pregnancy and child urinary BPA concentrations at ages 5, 7, and 9 with behavioral problems.	No associations were observed with prenatal BPA concentrations. However, there was an association between childhood urinary BPA concentrations and increased ADHD behavior in boys and girls at age 7.
Tewar et al. (24)	FI: 3,8 Q1 (25/176)	Number of participants: 460. Target group: children aged 8–15 years. Neurological assessment: DSM-IV criteria for ADHD using the Diagnostic Interview Schedule for Children-IV. Enrollment period: 2003 to 2004. BPA concentration: one urine sample	Transversal	Determine the association between childhood BPA exposure and ADHD in a national sample of American children aged 8 to 15 years, and whether sex modifies this association.	Higher BPA concentrations were associated with ADHD, with these associations being stronger in boys than in girls.
Foreman et al. (25)	FI: 3,4 Q2 (136/272)	Number of participants: 101 (55 boys and 46 girls). Target group: Adolescents aged 13–15 years. Neurological assessment: Test of Everyday Attention for Children (TEA-Ch) and the Dutch Attention Deficit Hyperactivity Disorder Questionnaire (AVL). Enrollment: 2014–2016. BPA concentration: Urine sample.	Cohorts	To determine if urinary concentrations of bisphenols are associated with attention and concentration in adolescents overall and by sex.	Bisphenol concentrations were not associated with attention and concentration scores after adjusting for confounding factors.
Arbuckle et al. (26)	FI: 3,1 Q2 (113/259)	Number of participants: 211 children. Target group: Children aged 6 to 11 years. Neurological assessment: Canadian Health Measures Survey (CHMS) and Strengths and Difficulties Questionnaire (SDQ). Enrollment: 2007–2009. BPA concentration: Urine and blood samples.	Transversal	Explore the potential relationships between exposure to BPA, phthalates, and lead to observe various indicators of behavioral or learning difficulties in children.	There is an association between BPA and ADHD, as solidly supported by the literature, although the measure is indirect.

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Table 1 (*continued*)

Author	Quality index	Characteristics	Type of study	Objectives	Outcomes
Yoo et al. (27)	FI: 2,5 Q3 (200/273)	Number of participants: 195 children diagnosed with ADHD and 249 children in the control group. Target group: Children aged 6–10 years. Neurological assessment: the Korean version of the ADHD Rating Scale (K-ARS) and the Behavior Assessment System for Children (BASC-2), cognitive function was assessed with the Continuous Performance Test (CPT). Enrollment from 2008 to 2010. BPA concentration: Urine analysis of mothers during pregnancy and of children at 5 years old.	Cases and controls	Investigate the association between BPA exposure and behavioral and cognitive function in children with ADHD and healthy controls.	BPA exposure was associated with unfavorable behavioral and cognitive outcomes.
Tran and Miyake (28)	FI: 1,9 Q3 (218/293)	7 BPA studies	Review study	Examine whether exposure to environmental toxins (maternal smoking, bisphenol A, phthalates, and heavy metals) during fetal and infant development affects the risk of neurodevelopmental disorders.	The susceptibility of neurodevelopmental disorders to exposure to toxic substances is not limited to the gestational period, but extends into the postnatal period as well.

with hyperactivity in both boys and girls (15). Hansen JB, et al. did not find an association between maternal BPA exposure and ADHD at age five, indicating no observed correlation in their study. In total 658 participants had BPA data and CBCL1½-5 data at age two including 427 participants at age five. BPA was detected in 85.3 % of the urine samples with a median concentration of 1.2 ng/mL. Women who were overweight, had never given birth, had lower education levels, or had never exclusively breastfed, had higher BPA levels. But guidelines to keep people safe were not exceeded (16). Jensen et al. found no association between prenatal BPA exposure and ADHD-related behaviors. The study involved 2217 Caucasian children, with BPA detected in 85.3 % of maternal urine samples at a median of 1.2 ng/mL. Higher BPA levels were observed in women with lower education, primiparous status, overweight, and those who did not breastfeed. However, only pre-pregnancy BMI was statistically significant. No safety limits were exceeded (17). Li et al. found that higher BPA levels were associated with an increased risk of ADHD, especially in boys. The study included 465 children, of whom 215 were diagnosed with ADHD. Over 90 % of urine samples contained BPA, with significantly higher levels in the ADHD group—nearly double in unadjusted values and almost triple when adjusted for creatinine. Safety limits were not mentioned (18). Huang et al. found that high prenatal BPA exposure was associated with increased ADHD symptoms in 3 year-old children but not in 4 year-olds. In this study of 1783 pregnant women, with a median BPA serum concentration of 0.23 ng/mL, boys exhibited more behavioral issues, including ADHD and autism-related behaviors, while girls had more emotional symptoms. Higher prenatal BPA levels were linked to an increased risk of behavioral problems and inhibitory control issues, particularly among children with the highest exposure. No safety limits were mentioned for the detected BPA levels (19). Minatoya and Kishi, suggested a consistent association between ADHD symptoms and prenatal and concurrent BPA exposure, indicating that studies on this exposure included between 191 and 1080 children, aged 6 months to 15 years. BPA exposure, measured in maternal and child urine and umbilical cord blood, has been associated with negative effects on neuropsychological development, such as behavioral problems, anxiety, and decreased IQ. In some cases, BPA levels exceed established safety limits, and the effects are more pronounced at younger ages and in girls (20). Moore et al. found a moderate to high association between BPA and ADHD. Three studies on early-life BPA exposure and hyperactivity showed significant effects, particularly on hyperactivity, with differences between sexes and exposure windows. However, these studies did not detail the exact number of children or specific BPA levels in bodily fluids, nor did they report that safety limits were exceeded (21). Tsai et al. found that BPA levels were higher in children with ADHD. However, this difference was not statistically significant. This study exam-

ined 98 boys and 32 girls with diagnosed ADHD and 42 boys and 26 girls as controls. There was a relationship between urinary concentrations of EDCs (MBzP, MEHP, MEP, and BP) and serum gonadal hormones. Boys with ADHD had increased testosterone levels associated with increased urinary MBzP and MEHP levels. In contrast, girls with ADHD had increased LH and testosterone levels associated with increased urinary MEP and BP levels. The research did not specify whether these EDC levels would still be safe (22). Harley et al. observed an association between childhood exposure to BPA and ADHD symptoms at age seven, although no prenatal associations were found. The study included young mothers and their children, as well as a group of 5 year-olds. The children's BPA levels were approximately twice as high as in their mothers' during pregnancy, with average concentrations of 2.5 μg/L in the children and 1.1 μg/L in the mothers. These levels were lower than those found in the general population of the United States (3.6 μg/L in children aged 6–11 years). The study did not specify whether these levels exceeded established safety limits (23). In 2016, Tewar et al. discovered that higher levels of BPA were linked to ADHD, especially in boys. The average age of the 460 children in the study was 11.5 years. Almost all urine samples contained detectable levels of BPA. Most values were above the limit of detection. 7.1 % of the participants had a diagnosis of ADHD, while those individuals with BPA concentrations above the median were more likely to be diagnosed. However, the study did not specify whether these concentrations exceeded safety limits (24). Foreman et al. did not find an association between bisphenol concentrations and attention or concentration after adjusting for confounding factors. The study involved 101 adolescents (55 boys and 46 girls) aged 13–15 years. Concentrations of parabens and bisphenols (BPA, BPF, BPS) were measured in urine using standard analytical techniques, such as chromatography coupled with mass spectrometry (e.g., LC-MS or GC-MS). Attention and concentration were assessed using validated neuropsychological standard tests. 12 adolescents (four girls and eight boys) were diagnosed with ADHD or ADD or were receiving treatment with psychostimulants. The study did not specify whether the levels of these compounds exceeded safety limits (25). Arbuckle et al. discovered a correlation between BPA exposure and ADHD in children aged 6–11 years. Their study revealed that many children had significant exposure to environmental toxins, such as BPA and lead. BPA urinary levels ranged from a geometric mean of 1.31–7.24 μg/L. Blood lead levels also exceeded safety thresholds. These chemicals have been associated with cognitive and behavioral issues, raising concerns about their potential impact on child development (26). Yoo et al. found a link between BPA exposure and negative behavioral and cognitive outcomes in children. The study involved 444 children aged 6–10 years, of whom 195 were diagnosed with ADHD and 249 were healthy controls. Urinary BPA levels were measured using mass spectrometry, and behavioral and cognitive functions were assessed using tools such as the K-ARS, BASC-2, and ADS. The research was approved by the institutional review board of Dankook University Hospital (27). Tran NQ and Miyake K concluded that the vulnerability to neurodevelopmental disorders from toxic substances spans from pregnancy to postnatal stages. A study of 244 mothers and their 3 year-old children found that higher levels of BPA in maternal urine were associated with increased behavioral issues in children, particularly anxiety and hyperactivity, especially in girls. It was noted that BPA and phthalates are commonly found in human urine at concentrations that exceed safety limits and are linked to developmental and behavioral issues (28).

Regarding research on the effect of PCBs on ADHD symptoms, Table 2 shows that Pessah et al. reviewed several studies on PCB exposure in children aged 3–11 years and found evidence that PCBs are developmental neurotoxins associated with cognitive deficits (29). Verner et al. conducted the New Bedford Cohort Study which examined prenatal PCB exposure through maternal cord blood levels. The study involved 441 children and the average PCB-153 concentration was 53.7 ng/g lipid. The study identified a significant association between elevated prenatal PCB-153 levels and ADHD-related behaviors in 8 year-old children, particularly among those in the highest exposure quartile. Postnatal levels of PCB-153 generally declined, except among breastfed infants, who exhibited continued increases during breastfeeding (30). Cheslack-Postava et al. did not find a significant association between maternal prenatal levels of PCB or DDE and an ADHD diagnosis in offspring (31). Lenters et al. also found no significant association between prenatal PCB exposure and ADHD in children aged 3–12 years. The study analyzed 359 children with ADHD and 359 controls and focused on the impact of persistent organic pollutants (POPs), such as PCBs and DDE. The study revealed that, while maternal PCB levels were similar in both groups, and DDE levels were slightly higher in ADHD cases, these pollutants were not significantly linked to an ADHD diagnosis after adjusting for various factors (32). Caspersen et al. in a study involving 1024 Norwegian preschool children (546 boys and 478 girls), found no significant link between maternal exposure to PCB-153 and dl-compounds during pregnancy and ADHD symptoms or cognitive function in preschoolers. Despite high levels of exposure to these compounds, 97.8 % of the mothers were below the tolerable weekly intake (TWI) for these substances, no adverse effects were observed in their children. Notably, 80 % of those exceeding the TWI for dl-compounds also had elevated PCB-153 levels, but no correlations with negative child outcomes were found (33). Neugebauer et al. suggested that prenatal and perinatal exposure to PCBs and PCDD/Fs may

Table 2. Description of studies related to PCB exposure and effects on ADHD symptomatology.

Author	Quality index	Characteristics	Type of study	Objectives	Outcomes
Pessah et al. (29)	FI: 14, 25 Q1 (4/204)	Studies before 2018 using PubMed: 12 articles on PCBs in children aged 3–11 years.	Literature review	Reviewing whether PCB exposure is related to cognition, attention, behavior regulation, ADHD, and ASD.	There is evidence that PCBs are neurotoxic to development and have been associated with cognitive deficits.
Verme et al. (30)	FI: 8,44 Q1 (5/ 225)	Number of participants: 441. Target group: 8 year-old children. Neurological assessment: Conners' ADHD Index, Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). PCB concentration: Measurement of umbilical cord blood. Enrollment between 1993 and 1998.	Epidemiology	Evaluate whether estimated levels of PCB in serum during childhood are associated with ADHD-related behaviors in 8 year-old children.	Serum levels of PCB-153 in umbilical cord blood were associated with ADHD-related behaviors.
Cheslack-Postava et al. (31)	FI: 8,3 Q1 (16/207)	Number of participants: 359 ADHD cases and 359 controls. Neurological evaluation: CRHC diagnosis of ADHD using DSM-IV criteria. PCB concentration: through maternal sera. Enrollment: cases born in 1998 or 1999.	Cases and controls	Determining if prenatal maternal levels of PCB or DDE are associated with the diagnosis of ADHD in offspring.	Maternal levels of PCB or DDE above the 75th percentile showed no association with ADHD in offspring.
Lenters et al. (32)	FI: 7,5 Q1 (18/265)	Number of participants: 1199 mother-child pairs. Target group: Children aged 3–12 years. Neurological assessment: Diagnostic and Statistical Manual of Mental Disorders (DSM-5). PCBs concentration: Analysis of breast milk. Enrollment: Between 2002 and 2009.	Prospective cohorts	Investigate chemical exposures in early life in relation to ADHD.	No associations were found between PCBs and ADHD.
Caspersen et al. (33)	FI: 7,08 Q1 (7/229)	Number of participants: 1024 mother-child pairs. Target group: 3.5 year-old children. Neurological evaluation: DSM-IV diagnosis and Child Behavior Checklist for ADHD. PCBs concentration: assessed through an FFQ questionnaire answered in week 22 of gestation. Enrollment: Pregnant women recruited from 1999 to 2008 and children from 2007 to 2011 at 3 years old.	Prospective longitudinal	That's a solid academic translation! It conveys the meaning accurately and concisely.	No evidence was found to suggest that variation in current PCB exposure in Norway is associated with variations in ADHD symptoms.
Neugebauer et al. (34)	FI: 3,9 Q1 (17/173)	Number of participants: 234 mother-child pairs. Target group: 8 and 9 year-old children. Neurological assessment: KITAP, FBB-ADHS, and WISC-IV. PCB concentration: Blood analysis at week 32 of pregnancy and in breast milk 2 weeks after birth. Mothers were enrolled between 2000 and 2002, and neurological assessments were collected between 2009 and 2011.	Cohorts	Low-level exposure to these compounds is being investigated in relation to children's attention.	Perinatal and prenatal exposure to PCBs and PCDD/Fs may influence attention performance in healthy children with low environmental levels.
Newman et al. (35)	FI: 2,7 Q2 (34/88)	Number of participants: 271. Target group: Adolescents aged 10–16.9 years. Neurological assessment: Second edition of the Attention Deficit Disorder Evaluation Scale (ADDES) and Conners Rating Scales. PCBs concentration: Blood extraction taken after an 8 h fast.	Transversal	Analyze the relationship between PCB levels in adolescents' serum blood and ADHD behavior derived from ratings provided by parents and teachers.	No evidence was found of negative effects of PCB levels in adolescents' blood on ADHD-like behavior.

(*continued on next page*)

Table 2 (*continued*)

Author	Quality index	Characteristics	Type of study	Objectives	Outcomes
Polanka et al. (36)	FI: 1,09 Q3 (117/62)	After 2000, 31 studies were included, of which 13 were about PCBs.	Review	Investigate the association between ADHD and industrial chemicals, such as organophosphates, PCBs, lead, mercury, and manganese.	Exposure to organochlorine pesticides and PCBs was associated with ADHD-like behaviors.

influence children's attention performance, even at low environmental exposure levels. The study included 117, 8 year-olds and 114, 9 year-olds, 53.8 % of whom were male. The focus was on maternal exposure to pollutants such as PCBs, PCDD/Fs, and lead, and their potential impact on attention and ADHD-related behaviors. Although moderate levels of these environmental pollutants were detected, no significant associations were observed with adverse outcomes. Exposure levels to lead (median 20 μg/L in maternal blood) and PCBs (median 0.16 μg/g lipid base) remained below safety thresholds, and no evidence of harm was found in relation to these factors (34). Newman et al. found no evidence that PCB levels in adolescents' bloodstream adversely affect ADHD-like behavior. The study involved 271 adolescents (131 males and 140 females) and revealed that PCB levels did not exceed safety limits. No significant association was observed between PCB exposure and ADHD symptoms. Analysis showed that adolescents with lower PCB exposure had fewer problematic scores on the impulsive-hyperactive scale. However, overall, there were no substantial effects on ADHD-related scores (35). Polańska et al. identified an association between exposure to organochlorine pesticides and PCBs and ADHD-like behaviors (36).

Discussion

Exposure to BPA and Its Association With ADHD

BPA is a chemical compound used in the manufacture of plastics and resins. It is found in many consumer products, such as water bottles, food containers, and kitchen utensils. Concerns have been raised about the potential effects of BPA on ADHD (17).

Early exposure to BPA, including during pregnancy, has been a subject of interest because early neurological development is believed to be more susceptible to environmental influences. Several studies have suggested that prenatal exposure to BPA may increase the risk of ADHD in offspring, but further research is needed to confirm these findings. These studies have explored the possible association between BPA exposure and ADHD, particularly in children. While some have found an association between BPA exposure and an increased risk of developing ADHD symptoms, these results have not established a definitive causal relationship (16–20,22,26).

It is important to note that BPA exposure may be only one factor among many contributing to the development of ADHD. Other factors, such as environmental, genetic, and psychosocial influences, may also play a significant role (19).

A recent study conducted by Kim et al., suggests that there is a significant association between BPA, BPF, BPS levels, and ADHD symptoms in children aged 4–8 years, with a nonlinear dose-response relationship at 6 years. In girls, the positive associations were significantly stronger at 6 years than in boys. The reason for these stronger associations in girls is unclear, but differences in exposure, timing of assessment, and measurement tools could be influencing the results. Further studies are needed to better understand the relationship between bisphenols and developmental disorders, as well as the potential underlying mechanisms involved (14).

A systematic review and meta-analysis study that included animal and human research found that early BPA exposure was associated with hyperactivity in children. However, differences were observed regarding sex and exposure windows. This sex distinction may be due to the fact that girls are sometimes underdiagnosed. After all, their symptoms are less evident and may go unnoticed more frequently. Furthermore, the effects of endocrine disruptors often fluctuate by sex, although the mechanisms are not fully understood. These results suggest that further research is needed to understand these effects and potential sex variations fully (15).

In two studies conducted with the prospective Odense Child Cohort, which began in 2010, researchers investigated the possible relationship between prenatal exposure to BPA and neurodevelopmental disorders such as ADHD, and its potential sex-specific effects. BPA levels were measured in urine samples from pregnant women, and found that 85.3 % of the samples contained BPA. While no association was found between prenatal BPA exposure and ADHD symptoms, there was a trend indicating a reduced risk of ADHD in boys and an increased risk in girls with the highest BPA exposure levels. The lack of association may be related to the children's age, as ADHD symptoms are rarely present at two years old (16,17).

In a case-control study conducted by Li et al., a significant association was identified between BPA exposure and ADHD. The BPA levels in the ADHD group were twice as high as those in the control group. Additionally, a slight sex difference was observed, with boys being more affected by BPA levels than girls. However, this difference was not statistically significant when adjusted for urinary creatinine. Nevertheless, further clinical studies are needed to support the hypothesis that BPA exposure could damage neurons and alter children's behavior (18).

Huang et al. demonstrated that higher prenatal BPA concentrations were associated with an increased risk of behavioral and cognitive function problems in 3 year-old children. They also found age- and sex-specific effects of BPA. Girls were more susceptible to the adverse effects of BPA on cognitive function and behavior. Furthermore, the relationship between prenatal BPA concentrations and behavioral problems was stronger in 3 year–olds than in 4 year-olds (19).

A narrative review conducted by Minatoya and Kishi, examined the relationship between ADHD and BPA exposure during both the prenatal and postnatal periods. The review identified an association between prenatal BPA exposure and various neurobehavioral outcomes in children. These outcomes include externalizing problems such as hyperactivity, aggression, loss of emotional control, impulsivity, and inattention, as well as internalizing problems such as anxiety, depression, social impairment, mood instability, and dependency. Furthermore, a relationship was observed between prenatal BPA exposure and ADHD, particularly in boys (20).

Moore et al. conducted a scoping review examining the association between ADHD and environmental chemicals. They found that early BPA exposure significantly increases ADHD incidence, with noted differences between sexes and exposure windows (21).

A cross-sectional study by Tsai et al., examined the effects of EDCs on the susceptibility to ADHD and gonadal hormones. The results indicated that children with ADHD had higher levels of EDCs than the control group (22).

Harley et al. investigated the relationship between early BPA exposure and behavioral problems such as anxiety, depression, and hyperactivity in children. BPA levels were measured in the urine of mothers during pregnancy and in their offspring at age five. Children's behavior was assessed through reports from mothers and teachers, and through direct evaluations at ages seven and nine. Higher prenatal BPA concentrations were associated with internalizing problems (e.g., depression and anxiety) and concentration difficulties at age seven. Additionally, there was evidence of an association with increased internalizing problems and ADHD behaviors in both boys and girls, as well as increased externalizing behaviors in girls (23).

Zhou et al. investigated the association between urinary BPA concentrations and the prevalence of ADHD in American children aged 8–15 years. A stronger association between BPA concentrations and ADHD was observed in boys compared to girls. Boys with BPA concentrations at or above the median were nearly 11 times more likely to have ADHD. Due to the sample size, however, these findings should be interpreted with caution (24).

Foreman et al. analyzed the relationship between urinary concentrations of various bisphenols (BPA, BPF, and BPS) and five parabens (MetP, EtP, ProP, ButP, and BenP) and symptoms of attention, hyperactivity, and impulsivity in adolescents. The study included 101 adolescents, aged 13–15, and evaluated the concentrations of five parabens and three bisphenols in their urine. Urinary accumulation of MetP, EtP, and ButP was associated with fewer ADHD-like behaviors; however, exposure to ProP may increase ADHD-like symptoms. Regarding bisphenols, no significant relationship was found between urinary concentrations of BPA, BPF, and BPS and attention and concentration after adjusting for confounding factors, such as urinary creatinine, age, sex, diet type, BMI, maternal age at birth, maternal education, and alcohol and cigarette consumption during pregnancy. This lack of significant association could be due to decreased BPA exposure with age, as metabolism increases with age and younger children are more frequently in contact with plastics (25).

In another cross-sectional study, Arbuckle et al. examined the potential association between exposure to BPA and phthalates and learning and behavioral problems in children. Using data from the Canadian Health Measures Survey (CHMS), the researchers assessed urinary concentrations of BPA, phthalates, and lead, and collected information on children's learning and behavioral problems using the Strengths and Difficulties Questionnaire (SDQ). While an association was found between BPA exposure and the use of psychotropic medications for ADHD in children, no significant associations were observed with behavioral or emotional problems themselves. It is important to note that this study has limitations due to its cross-sectional nature, which prevents establishing causal relationships. Nevertheless, the results suggest that exposure to environmental chemicals at an early age may contribute to the development of learning and behavioral problems in children (26).

In a case-control study, Yoo et al. found an association between BPA exposure and more severe ADHD symptoms, including hyperactivity, aggression, anxiety, and depression in children. The researchers observed sex differences, finding more significant associations in boys than in girls. These results imply that BPA exposure could adversely affect behavioral and cognitive outcomes, especially in children with ADHD (27).

Finally, Tran et al., analyzed the relationship between ADHD, BPA, and phthalates, and found that symptoms of ADHD and aggressive behavior were related to elevated concentrations of BPA in maternal urine during gestation.

This supports the Developmental Origins of Health and Disease (DOHaD) hypothesis, which suggests that environmental factors during fetal and infant development may influence the risk of neurodevelopmental disorders (28).

Exposure to PCBs and Their Effects on ADHD Symptoms

Polychlorinated biphenyls (PCBs) are persistent organic pollutants known for their durability and lipophilic properties. They accumulate in the body and are transferred from mother to child during both the prenatal and postnatal stages. Fetal exposure to PCBs depends on the mother's long-term contact with these substances through diet, as well as during the early fetal and postnatal stages. Exposure during these critical periods can affect cellular signaling processes, endocrine functions, neurotransmitter synthesis, and the organization of the developing brain. PCBs are found in contaminated foods, primarily through fish, which leads to bioaccumulation in humans (33).

Exposure to PCBs has been associated with effects on the nervous system, cognitive function, and behavior. Some studies have found associations with ADHD-like symptoms. However, it is important to note that research in this field is still evolving, and results may vary between studies (35).

A 2019 review by Pessah et al. examined the relationship between prenatal PCB exposure and child development. They found associations with traits related to ADHD, such as attention problems and hyperactivity. Although the results were mixed, most studies indicated that prenatal PCB exposure is associated with poor cognitive functioning and behavioral problems. The review highlighted the sensitivity of the gestational period and early childhood, suggesting that PCB exposure during these periods could significantly impact cognitive development and behavior (29).

In another study, Verme et al. analyzed the relationship between postnatal exposure to PCB-153 and ADHD-related behaviors in children. A significant association was observed between PCB-153 levels in umbilical cord blood and behaviors associated with ADHD in children. There was a positive correlation between the total duration of breastfeeding and PCB-153 levels in children's serum. This correlation gradually increased over time. The study highlighted that, during the first year, the duration of breastfeeding was the most influential model parameter, suggesting that the initial breastfeeding period could be crucial in terms of PCB exposure and its impact on the development of ADHD-associated behaviors. The study suggests that children predisposed by early genetic and environmental factors may be more susceptible to both prenatal and postnatal PCB exposure (30).

In a case-control study by Cheslack-Postava et al., the relationship between maternal prenatal PCB levels and the clinical diagnosis of ADHD in offspring was examined. The results indicated no significant association between maternal total PCB levels and the likelihood of children being diagnosed with ADHD. Although no association was found, the need to further investigate the complex links between prenatal exposure to pollutants and neuropsychiatric disorders is emphasized. This recognizes the potential interactions with genetic factors and the importance of considering both clinical and subclinical outcomes (31).

In a 2019 prospective cohort study by Lenters et al., no clear associations were found between PCB exposure and ADHD diagnosis. However, higher concentrations of other substances, such as BDE-47, PFOS, PCB-153, and p,p′-DDE were identified in breast milk. Early exposure to B-HCH and PFOS was associated with an increased risk of ADHD, while higher levels of p,p′-DDT were associated with a lower likelihood of ADHD. These findings suggest that different compounds in breast milk may affect the risk of developing ADHD in different ways. No clear relationship was established between PCBs and the ADHD diagnosis in this context (32).

In a 2016 study by Caspersen et al., researchers investigated the effect of maternal dietary exposure to PCBs and dioxins during pregnancy on ADHD development and cognitive function in preschool children. They did not find significant associations between PCB levels and ADHD symptoms or executive functions in the evaluated children. However, a significant reduction in expressive language was observed in girls whose mothers were exposed to these substances during pregnancy (33).

A cohort study by Neugebauer et al., found that exposure to certain contaminants such as PCBs and PCDD/F was found to be associated with changes in attention performance on specific tests. However, the associations were mostly small and not significant. Measurements of contaminants in both breast milk and blood yielded similar results, suggesting some consistency in the findings regardless of the sample type used to measure exposure. It was suggested that there might be a critical period during prenatal development in which exposure to these contaminants could have a more significant impact on attention performance (34).

A study by Newman et al., the possible association between PCB levels and ADHD in adolescents was analyzed. The researchers did not find a statistically significant association between PCB levels and ADHD in the adolescents studied. Furthermore, parental reports indicated that adolescents with higher PCB levels showed fewer hyperactivity issues. Negative confounding variables, such as socioeconomic status and breastfeeding, were considered, but no evidence was found that these variables interfered with the results. Future research is encouraged to examine other behavioral outcomes, use more sensitive measures, and conduct studies with adolescent populations to better understand the effects of PCBs at different stages of development (35).

In their 2013 review study, Polanka et al. examined several works conducted between 2002 and 2013 that suggest an association between prenatal PCB exposure and attention problems, impulsivity, and variations in response time. A specific study conducted on children born near a harbor contaminated with PCBs was mentioned, where associations were found between PCB levels in umbilical cord blood and attention problems, alertness, response quality, attention costs, and other measures associated with attention. It was concluded that PCB exposure could be associated with ADHD (36).

In summary, the reviewed studies on the relationship between exposure to PCBs during pregnancy and after birth, and ADHD, show mixed results. Some studies do not find a significant association between PCB levels and ADHD, while others suggest possible links, particularly to attention and hyperactivity problems. The duration of breastfeeding and the prenatal period are presented as critical moments for the potential influence of PCBs on the development of behaviors associated with ADHD. The complexity of the results underscores the need for continued research to better understand these connections in the context of genetic and environmental factors.

Several studies suggest that these endocrine-disrupting chemicals may also be associated with other mental health issues. For example, research indicates that exposure to BPA and PCBs early in life can impact the development of conditions such as anxiety, depression, emotional regulation difficulties, and cognitive impairments. Harley et al. found that prenatal BPA exposure was associated with an increased risk of internalizing problems, including depression and anxiety, as well as externalizing behaviors in both boys and girls (23). Similarly, Huang et al. found that prenatal BPA levels were connected to behavioral and cognitive function issues in children, with girls appearing to be more vulnerable to these negative effects (19). Furthermore, research on PCBs (29,30) has revealed that early exposure, especially during critical developmental periods such as the prenatal and postnatal stages, can impair cognitive functioning and contribute to attention problems. These commonly discussed disorders imply that endocrine disruptors might have a wider impact on mental health. While studies have explored these connections, further evidence is necessary to fully understand the underlying mechanisms. Furthermore, various factors such as genetics, sex, and the nature of the prenatal and postnatal environment may influence these effects. This highlights the need for a thorough approach to evaluating the risk of psychiatric disorders linked to chemical exposure.

It is also essential to examine sex differences in ADHD prevalence. Research indicates that boys are diagnosed with ADHD more frequently than girls, with an approximate population ratio of 3:1. This disparity may stem from various factors, including how symptoms are expressed and the methods used for diagnosis. Symptoms in girls tend to be more subtle, which may result in underdiagnosis. Additionally, girls with ADHD often present more internalizing symptoms, such as anxiety and depression, while boys typically exhibit externalizing symptoms, such as hyperactivity and impulsivity (16,17,19). This distinction may lead to boys being identified with ADHD at an earlier age. However, some experts argue that the differences in ADHD prevalence are not purely biological, but also reflect social and cultural factors. This highlights the importance of paying closer attention to how ADHD manifests in girls and reconsidering the diagnostic criteria (20,21). Recognizing these sex-specific differences is vital for improving diagnosis and treatment for all children affected by ADHD.

EDCs such as BPA and PCBs have significant neurotoxic effects, and their impact on thyroid function is a key mechanism. Studies suggest that exposure to EDCs, particularly during prenatal stages, can disrupt thyroid hormone levels and affect neurodevelopmental processes (16,23). Thyroid hormones play a crucial role in brain development and these alterations can lead to impairments in neurogenesis, synaptic plasticity, and neuronal migration, all of which are critical for cognitive and behavioral development (19,30). PCBs, for instance, accumulate in lipid-rich tissues, including the brain, due to their high lipophilicity, which enhances their neurotoxic potential (29). Furthermore, EDCs contribute to oxidative stress and inflammation in neural circuits, which further impact brain function. Such mechanisms may explain the association between BPA and PCBs with neurodevelopmental disorders like ADHD, underscoring the importance of understanding the relationship between EDC exposure and thyroid hormone dysregulation to mitigate potential risks.

Limitations of the Study

A. Several studies have suggested an association between BPA exposure and ADHD, but a definitive causal relationship has not yet been established. Most studies are observational, which limits the ability to determine causality.
B. Studies present inconsistent results. Some find significant associations, while others do not. This may be due to differences in study design, the studied population, and measurement methods.
C. BPA exposure may be correlated with other risk factors for ADHD, such as environmental, genetic, and psychosocial factors, which are often not adequately controlled in studies.
D. Sex differences in ADHD diagnosis may influence results. Girls are often underdiagnosed, which could affect how the relationship between BPA exposure and ADHD is interpreted.
E. Many studies are cross-sectional, which prevents the determination of whether BPA exposure precedes the development of ADHD symptoms.

F. Differences in measurement tools and assessment timings may affect the results. BPA exposure and ADHD symptom assessment can vary considerably between studies.
G. Some studies have small sample sizes, which limits the generalizability of the results and the ability to detect significant associations.

Strengths of the Study

A. This review encompasses a wide range of research examining the relationship between BPA exposure and ADHD, providing a comprehensive insight into the topic.
B. Various types of studies were used, including cohort studies, case-control studies, systematic reviews, and meta-analyses, which enriched the understanding of the issue.
C. Several studies attempt to control for confounding factors such as sex, age, exposure to other endocrine disruptors, and socioeconomic factors.
D. Some studies specifically investigate sex differences in the relationship between BPA exposure and ADHD, providing valuable insights into potential variations in susceptibility.
E. Despite limitations, many studies have found a significant association between BPA exposure and ADHD symptoms. This suggests that there may be a potential relationship worthy of further investigation.
F. Studies consider both prenatal and postnatal exposure to BPA, highlighting the importance of critical developmental windows in susceptibility to its effects.
G. Various assessment tools are used to measure ADHD symptoms, including parent and teacher reports, as well as direct clinical assessments.

Conclusions

There is growing concern about BPA exposure due to its ubiquitous presence in everyday consumer products and its potential association with ADHD. Several studies suggest that prenatal exposure to BPA and PCBs increases the risk of ADHD in offspring, though the results do not establish a definitive causal relationship. Prenatal exposure to BPA and PCBs may affect child behavior; however, further research is needed to fully understand these effects, including potential sex differences. There is a relationship between BPA levels and ADHD symptoms, especially in children aged six to eight years, with differences observed between boys and girls. This relationship may be influenced by factors such as sex, age, timing of exposure, and diet, as observed with vitamin D. There is increased sensitivity to PCB exposure during the gestation and lactation period, which could have a significant impact on cognitive development and behavior. Despite these findings, further research is needed to better understand the underlying mechanisms of the association between BPA, PCBs, and ADHD. Prenatal exposure to BPA and PCBs may affect child behavior, but more research is needed to fully understand these effects and potential sex variations.

In conclusion, it is crucial to establish and regulate safe exposure levels for BPA and PCBs, as these chemicals are present in environmental sources like water, soil, and food. Regulatory bodies such as the Environmental Protection Agency (EPA) and the European Food Safety Authority (EFSA) have set specific limits for BPA in food products, and acceptable levels in water and soil are also monitored to prevent excessive exposure. For example, the EPA has set the maximum contaminant level for BPA in drinking water at 0.5 μg/L. Similarly, PCB levels in water and soil are regulated to ensure they remain within safe limits. However, concerns persist about the endocrine-disrupting effects of chronic, low-level exposure, indicating that these safety thresholds may require reevaluation based on new evidence. This underscores the need for ongoing research to better understand the long-term impacts of these chemicals and to adjust safety standards accordingly to safeguard public health.

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Data availability

The data that support the findings of this study are openly available in Figshare at http://doi.org/10.6084/m9.figshare.25721478.

Conflicts of Interest

The authors declare no conflicts of interest.

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